WATER & SEWAGE WORKS

REFERENCE *and* DATA EDITION

JUNE 1, 1955

Water and Sewage Works Presents Its 1955 R & D Edition

For 20 Years
Water & Sewage Works magazine has issued an annual reference and data section.

This Edition
is the second of these useful handbooks to be published as a separate volume.

The Editors
have selected articles, tables and charts relating to various phases of water supply, sewage disposal and industrial waste problems. This year, for the first time the text material is presented in nine different sections dealing with specific phases of water and sewage works.

The Contents
provide reference and data material of value in management, functional operations, water treatment, sewage treatment, industrial waste, engineering fundamentals, and design and construction.

Information
presented in the 384 pages of this issue includes much new material and a variety of repeated material having basic value.

Subscribers
to Water & Sewage Works receive this new reference and data edition without charge.

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reference and data edition

WATER & SEWAGE WORKS reference and data edition

* JUNE 1, 1955

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WATER & SEWAGE WORKS

reference and data edition

✱ JUNE 1, 1955

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CLASSIFIED INDEX OF PRODUCTS

For the Index to the Reference and Data Material, and the Index to Advertisers, See the Rear Section of this Issue.

1R
ACID SULFURIC AND HYDROCHLORIC
Diamond Alkali Co.
Pennsylvania Salt Mfg. Co.

2R
ACTIVATED AND BLACK ALUM
General Chemical Div., Allied Chemical & Dye Corp.
Pennsylvania Salt Mfg. Co.

3R
ACTIVATED CARBON
Graver Water Conditioning Co.
Infilco, Inc.
Nichols Eng. & Research Co.
Stuart Corp.
West Virginia Pulp and Paper Co., Industrial Chemical Sales Div.

4R
ACTIVATED SILICA GENERATORS
Omega Machine Co.
Wallace & Tiernan, Inc.

5R
AERATION APPARATUS
American Water Softener Co., Inc.
American Well Works
Chicago Pump Co.
Dorr-Oliver, Inc.
General Filter Co.
Graver Water Conditioning Co.
Infilco, Inc.
Pacific Flush Tank Co.
Permutit Co.
Walker Process Equip., Inc.
Yeomans Bros. Co.

6R
AGITATORS
American Water Softener Co., Inc.
Dorr-Oliver, Inc.
General Filter Co.
Hardinge Co., Inc.
Infilco, Inc.
F. B. Leopold Co., Inc.
Link-Belt Co.
Stuart Corp.
Walker Process Equip., Inc.
Western Machinery Co.
Worthington Corp.

AIR BLOWERS
(See Blowers, Air)

AIR COMPRESSORS
(See Compressors, Air)

7R
AIR RELIEF VALVES
Darling Valve & Mfg. Co.
Rensselaer Valve Co.
Simplex Valve & Meter Co.

8R
ALTERNATORS, ELECTRIC
Allis-Chalmers Mfg. Co.
Electric Machinery Mfg. Co.
Fairbanks Morse & Co.
General Electric Co.
Henly-Ruff Co.
Smith & Loveless, Inc.

9R
AMMONIA, ANHYDROUS AND AQUA
General Chemical Div., Allied Chemical & Dye Corp.
Pennsylvania Salt Mfg. Co.

10R
AMMONIATORS
American Water Softener Co., Inc.
Everson Mfg. Co.
Fischer & Porter Co.
Proportioneers, Inc.

11R
ANTHRAFILT
Anthracite Equipment Corp.
Graver Water Conditioning Co.
Infilco, Inc.
Stuart Corp.
Walker Process Equip., Inc.

12R
ARRESTERS, FLAME
Pacific Flush Tank Co.

13R
ASH AND COAL HANDLING MACHINERY
Bucyrus-Erie
Chain Belt Co.
Jeffrey Mfg. Co.
Link-Belt Co.
Oliver Corp.
Pacific Flush Tank Co.
Stuart Corp.

BAR SCREENS
(See Screens, Sewage)

14R
BINS, STORAGE
Graver Water Conditioning Co.
Jeffrey Mfg. Co.
Natco Corp.
Nooter Corp.

15R
BITUMINOUS COATINGS AND LININGS
Alco Products, Inc.
Atlas Mineral Products Co.
The Carborundum Co.
Chemical Fire & Rust Proofing Co.
Pittsburgh Coke & Chemical Co.
Pressitite Engineering Co.

BLACK ALUM
(See Activated Alum)

BLEACHING POWDER
(See Calcium Hypochlorite)

16R
BLOWERS AIR, GAS
Allis-Chalmers Mfg. Co.
Chicago Pump Co.
De Laval Steam Turbine Co.
Homelite Corp.
Roots-Connersville Blower

BOILER BREECHINGS
(See Breechings, Steel)

17R
BOILER FEEDWATER TREATMENT AND EQUIPMENT
Allis-Chalmers Mfg. Co.
American Water Softener Co., Inc.
Builders-Providence, Inc.
Chemical Equipment Co.
Fischer & Porter Co.
General Filter Co.
Graver Water Conditioning Co.
Infilco, Inc.
Lakeside Engr. Corp.
Permutit Co.
Precision Chemical Pump Corp.
Roberts Filter Mfg. Co.

18R
BOILERS, GAS
American Radiator & Standard Sanitary Corp.

19R
BOOKS TECHNICAL
John Wiley & Sons, Inc.

BOXES, VALVE AND METER
(See Valve Boxes; Meter Boxes)

20R
BRASS GOODS
Grinnell Company
Mueller Co.
Welsbach Corp.

21R
BREECHING, STEEL
Nooter Corp.

BUCKET ELEVATORS
(See Conveyors and Conveying Equip.)

22R
BUFFER SOLUTIONS AND TABLETS
General Laboratory Supply Co.

BUTTERFLY VALVES
(See Valves, Butterfly)

23R
CABLE
General Electric Co.
General Laboratory Supply Co.

24R
CALCIUM HYPOCHLORITE
John Wiley Jones Co.
Olin Mathieson Chemical Corp.
Pennsylvania Salt Mfg. Co.
Proportioneers, Inc.

CARBON-ACTIVATED
(See Activated Carbon)

25R
CARBONATORS (Recarbonation)
American Well Works
General Filter Co.
Graver Water Conditioning Co.
Infilco, Inc.
Lakeside Engr. Corp.
Permutit Co.
Smith & Loveless, Inc.
Walker Process Equip., Inc.

26R
CASTINGS, IRON, STEEL, ALLOY STEEL, ETC.
ACF Industries, Inc.
Bethlehem Steel Co.
Cast Iron Pipe Research Assn.
Chain Belt Co.
Filer & Stowell Co.
Jeffrey Mfg. Co.
Link-Belt Co.
United States Pipe & Foundry Co.

27R
CATHODIC PROTECTIVE SYSTEMS
Chemical Fire & Rust Proofing Corp.
Electro Rust-Proofing Corp.
Smith & Loveless, Inc.

28R
CAULKING MACHINES AND TOOLS
Mueller Co.
Joseph G. Pollard Co., Inc.

29R
CEMENT ASBESTOS PIPE
Johns-Manville
Keasbey & Mattison Co.

30R
CEMENT GUN
Cement Gun Co.

31R
CEMENT LINING OF PIPE
Ace Pipe Cleaning, Inc.
Cast Iron Pipe Research Assn.
Centriline Corp.
Chemical Fire & Rust Proofing Corp.
James B. Clow & Sons

32R
CEMENTS, ACID PROOF AND ALKALI PROOF
Atlas Mineral Products Co.
Johns-Manville
J. W. Mortell Co.
Pennsylvania Salt Mfg. Co.

33R
CEMENTS, REFRACTORY
The Carborundum Co.
Johns-Manville
Norton Co.

34R
CEMENTS, SEWER PIPE
Atlas Mineral Products Co.
Hydraulic Development Co.
Johns-Manville
Pressitite Engineering Co.
Price Bros. Co.

35R
CEMENTS, WATER MAINS
Atlas Mineral Products Co.
Hydraulic Development Co.
Price Bros. Co.

36R
CHAINS (Elevating, Conveying and Power Transmission)
Chain Belt Co.
Hydraulic Development Co.
Jeffrey Mfg. Co.
Link-Belt Co.

37R
CHEMICAL, CONVEYING EQUIPMENT
Chain Belt Co.
Infilco, Inc.
Jeffrey Mfg. Co.
Link-Belt Co.

CHEMICAL CONTROL EQUIP.
(See Laboratory Apparatus and Reagents)

38R
CHEMICAL FEEDING AND PROPORTIONING EQUIP.
American Water Softener Co., Inc.
Bailey Meter Co.
Builders-Providence, Inc.
Bulkley, Dunton Processes, Inc.
Chemical Equipment Co.
Everson Mfg. Co.
Fischer & Porter Co.
General Filter Co.
Graver Water Conditioning Co.
Infilco, Inc.
Jeffrey Mfg. Co.
Komline-Sanderson Engineering Corp.
Lakeside Engr. Corp.
F. B. Leopold Co., Inc.
Omega Machine Co.
Permutit Co.
Precision Chemical Pump Corp.
Proportioneers, Inc.
Wallace & Tiernan, Inc.

39R
CHLORINATORS
American Water Softener Co., Inc.
Builders-Providence, Inc.
Chemical Equipment Co.
Everson Mfg. Co.
Fischer & Porter Co.
Precision Chemical Pump Corp.
Proportioneers, Inc.
Wallace & Tiernan, Inc.

CHLORINE CONTROL EQUIP.
(See Residual Chlorine Control)

CHLORINE DIOXIDE
(See Sodium Chlorite)

40R
CHLORINE, LIQUID
Diamond Alkali Co.
John Wiley Jones Co.
Pennsylvania Salt Mfg. Co.

41R
CLAMPS AND SLEEVES, PIPE
James B. Clow & Sons
Corey Mfg. Co.
Dresser Mfg. Div.
Mueller Co.

42R
CLAMPS, BELL JOINT
H. Y. Carson Co.
James B. Clow & Sons
Dresser Mfg. Div.
M. B. Skinner Co.

43R
CLAMPS, PIPE REPAIR
James B. Clow & Sons
Dresser Mfg. Div.
Mueller Co.
M. B. Skinner Co.

44R
CLARIFIERS, SEWAGE AND WATER
American Water Softener Co., Inc.
American Well Works
Bulkley, Dunton Processes, Inc.
Chicago Pump Co.
Dorr-Oliver, Inc.
General Filter Co.
Hardinge Co., Inc.
Infilco, Inc.
Lakeside Engr. Corp.
Link-Belt Co.
Permutit Co.
Walker Process Equip., Inc.
Yeomans Bros. Co.

CLAY PIPE
(See Vitrified Clay Pipe and Products)

45R
CLEANING WATER MAINS
Ace Pipe Cleaning, Inc.
Amercoat Corp.
Flexible Pipe Cleaning Co.
Flexible Sales Corp.
Infilco, Inc.
National Power Rodding Corp.
Robinson Pipe Cleaner Co.

46R
COAGULATING AIDS
The Carborundum Co.
Chemical Fire & Rust Proofing Corp.
Dorr-Oliver, Inc.
Infilco, Inc.
Link-Belt Co.
Pennsylvania Salt Mfg. Co.
Philadelphia Quartz Co.
Wallace & Tiernan, Inc.

COAL AND ASH HANDLING MACHINERY
(See Ash and Coal Handling Machinery)

47R
COATINGS, ACID AND ALKALI-PROOF
Amercoat Corp.
Atlas Mineral Products Co.
Chemical Fire & Rust Proofing Corp.
Hamilton Kent Mfg. Co.
Hercules Powder Co., Inc.
Heresite & Chemical Co.
Koppers Co., Inc.
J. W. Mortell Co.
Pittsburgh Coke & Chemical Co.

COATINGS AND LININGS
(See Bituminous Coatings and Linings)

48R
COCKS (Curb, Meter, Corp. etc.)
Crane Co.
Dezurik Shower Co.
Mueller Co.
Welsbach Corp.

COLLECTORS (Sludge)
(See Sludge Collectors)

COLORIMETERS
(See Photoelectric Colorimeters)

49R
COMBUSTION INDICATORS AND RECORDERS
Bailey Meter Co.
Arnold O. Beckman, Inc.
Minneapolis-Honeywell Regulator Co.
Permutit Co.

50R
COMMINUTING DEVICES
Chain Belt Co.
Chicago Pump Co.
Infilco, Inc.
Worthington Corp.

51R
COMPARATORS, COLOR
General Laboratory Supply Co.
W. A. Taylor & Co.

COMPOUNDS, JOINT
(See Jointing Compounds and Materials)

52R
COMPRESSORS, AIR
Allis-Chalmers Mfg. Co.
Le Roi Div., Westinghouse Air Brake Co.
Worthington Corp.
Yeomans Bros. Co.

53R
CONCRETE BREAKERS
Worthington Corp.

54R
CONCRETE HARDENER
Philadelphia Quartz Co.
Standard Dry Wall Products, Inc.

55R
CONCRETE MIXER
Chain Belt Co.
Worthington Corp.

56R
CONCRETE PIPE (Water and Sewage)
American Concrete Pressure Pipe Assn.
Price Bros. Co.

57R
CONDENSERS (Steam)
Allis-Chalmers Mfg. Co.
Worthington Corp.

58R
CONTRACTORS (Water and Sewage Work)
Ace Pipe Cleaning, Inc.
Ranney Method Water Supplies, Inc.

59R
CONTROLLERS FLOW, LEVEL, PRESSURE, TEMPERATURE
Bailey Meter Co.
Ernest Bernard Elec. Co.
Builders-Providence, Inc.
Fischer & Porter Co.
Foxboro Co.
General Electric Co.
Healy-Ruff Co.
Infilco, Inc.
Leupold & Stevens Instruments, Inc.
Minneapolis-Honeywell Regulator Co.
Simplex Valve & Meter Co.
Smith & Loveless, Inc.

60R
CONVEYORS AND CONVEYING EQUIPMENT
American Well Works
Builders-Providence, Inc.
Chain Belt Co.
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.
Link-Belt Co.
Morse Boulger Destruction Co.
Oliver Corp.
Omega Machine Co.
Stuart Corp.
Walker Process Equip., Inc.

61R
COPPER SULFATE
Tennessee Corp.

62R
COPPER TUBING AND RED BRASS PIPE
Mueller Co.

CORPORATION AND CURB COCKS
(See Cocks-Corp., Curb & Meter)

63R
CORROSION SUPPRESSION
Amercoat Corp.
Calgon, Inc.
Chemical Fire & Rust Proofing Corp.
Electro Rust-Proofing Corp.
Mueller Co.
Pipe Linings, Inc.
Pittsburgh Coke & Chemical Co.

64R
COUPLINGS AND CONNECTIONS, PIPE
A. M. Byers Co.
James B. Clow & Sons
Crane Co.
Dresser Mfg. Div.
Mueller Co.

65R
COUPLINGS, FLEXIBLE
Chain Belt Co.
James B. Clow & Sons
De Laval Steam Turbine Co.
Hamilton Kent Mfg. C.o
Jeffrey Mfg. Co.
Johns-Manville
Link-Belt Co.

CULVERT PIPE
(See Pipe, Culvert)

66R
CURB, BOXES
Alabama Pipe Co.
James B. Clow & Sons
Filtration Equipment Corp.
Mueller Co.

67R
DECHLORINATING EQUIPMENT AND CHEMICALS
American Water Softener Co., Inc.
Chemical Equipment Co.
Graver Water Conditioning Co.
Infilco, Inc.
Permutit Co.
Proportioneers, Inc.
Tennessee Corp.
Wallace & Tiernan, Inc.

68R
DE-MINERALIZATION EQUIPMENT (Water)
American Water Softener Co., Inc.
Bulkley, Dunton Processes, Inc.
Chemical Equipment Co.
Dorr-Oliver, Inc.
General Filter Co.
General Laboratory Supply Co.
Graver Water Conditioning Co.
Infilco, Inc.
Lakeside Engr. Corp.
Layne & Bowler, Inc.
Permutit Co.

69R
DEODORIZING (Service, Equipment, Chemicals, etc.)
Airkem, Inc.
American Water Softener Co., Inc.
Chemical Equipment Co.
Lakeside Engr. Corp.
Olin Mathieson Chemical Corp.
Reliance Chemicals Corp.
West Virginia Pulp & Paper Co., Industrial Chemical Sales Div.

70R
DIATOMITE FILTER SEPTUMS
American Water Softener Co., Inc.
Bulkley, Dunton Processes, Inc.
Carborundum Co.
Dorr-Oliver, Inc.
General Filter Co.
Graver Water Conditioning Co.
Infilco, Inc.
Lakeside Engr. Corp.
Proportioneers, Inc.

DIESEL ENGINES
(See Engines, Diesel)

71R
DIFFUSERS—PLATES, TUBES AND FITTINGS
American Well Works
The Carborundum Co.
Chicago Pump Co.
Filtros, Inc.
Infilco, Inc.
Link-Belt Co.
Walker Process Equip., Inc.

72R
DIGESTER EQUIPMENT (Sludge)
American Well Works
Chicago Pump Co.
Dorr-Oliver, Inc.
Hardinge Co., Inc.
Infilco, Inc.
Lakeside Engr. Corp.
Pacific Flush Tank Co.
Walker Process Equip., Inc.
Yeomans Bros. Co.

73R
DISTRIBUTORS (Sewage Filter)
American Well Works
Dorr-Oliver, Inc.
Infilco, Inc.
Lakeside Engr. Corp.
Pacific Flush Tank Co.
Smith & Loveless, Inc.
Walker Process Equip., Inc.
Yeomans Bros. Co.

74R
DRAINS, GUTTER, FLOOR
Chemical Equipment Co.
James B. Clow & Sons
Irving Subway Grating Co., Inc.

75R
DRILLING AND BORING EQUIPMENT
Bucyrus-Erie
Layne & Bowler, Inc.
Worthington Corp.

DRIVES, CHAIN
(See Chains)

76R
DRIVES, RIGHT ANGLE GEAR
De Laval Steam Turbine Co.
Link-Belt Co.
Payne Dean & Co.
U. S. Electrical Motors, Inc.

77R
DRIVES, V-BELT
Allis-Chalmers Mfg. Co.
Link-Belt Co.
Worthington Corp.

78R
DRYING SYSTEMS (Sludge)
Combustion Engineering, Inc.
Hardinge Co., Inc.
Komline-Sanderson Engineering Corp.
Link-Belt Co.
Morse Boulger Destruction Co.
Nichols Eng. & Research Corp.
Reliance Chemicals Corp.

79R

EARTH MOVING EQUIPMENT
Allis-Chalmers Mfg. Co.
Oliver Corp.

80R

EJECTORS, PNEUMATIC or STEAM
Blackburn-Smith Mfg. Co., Inc.
Chicago Pump Co.
Economy Pumps, Inc.
Lakeside Engr. Corp.
Smith & Loveless, Inc.
Worthington Corp.
Yeomans Bros. Co.

81R

ELECTRICAL CONTROL EQUIPMENT
Allis-Chalmers Mfg. Co.
Foxboro Co.
General Electric Co.
General Filter Co.
Smith & Loveless, Inc.
Westinghouse Electric Corp.

ELECTRICALLY OPERATED GATE VALVES
(See Valves, Motor Operated)

ELEVATING AND CONVEYING EQUIPMENT
(See Conveyors and Conveying Equipment)

82R

ENGINE-GENERATOR UNIT
Allis-Chalmers Mfg. Co.
Climax Engine & Pump Mfg. Co.
Fairbanks Morse & Co.
Homelite Corp.
Le Roi Div., Westinghouse Air Brake Co.
National Supply Co.
Worthington Corp.

83R

ENGINES DIESEL
Allis-Chalmers Mfg. Co.
Fairbanks Morse & Co.
Oliver Corp.
National Supply Co.
Worthington Corp.

84R

ENGINES, DUAL FUEL
Allis-Chalmers Mfg. Co.
Fairbanks Morse & Co.
National Supply Co.
Worthington Corp.

85R

ENGINES (Gas and Gasoline)
Allis-Chalmers Mfg. Co.
Climax Engine & Pump Mfg. Co.
Fairbanks Morse & Co.
Le Roi Div., Westinghouse Air Brake Co.
Oliver Corp.
Worthington Corp.

86R

ENGINES, SLUDGE GAS
Climax Engine & Pump Mfg. Co.
Fairbanks Morse & Co.
Le Roi Div., Westinghouse Air Brake Co.
National Supply Co.
Worthington Corp.

EXHAUSTERS, AIR
(See Pump, Vacuum)

EXPANSION JOINTS—PIPE
(See Joints—Expansion, Pipe)

87R

FANS, EXHAUST AND VENTILATING
Westinghouse Electric Corp.

FEED, CHEMICAL
(See Chemical Feeding Equipment)

88R

FEED WATER HEATERS AND FILTERS
American Water Softener Co., Inc.
Graver Water Conditioning Co.
Infilco, Inc.
Lakeside Engr. Corp.

89R

FENCE (Chain Link)
Continental Steel Co.

90R

FERRIC CHLORIDE
Infilco, Inc.
Omega Machine Co.
Pennsylvania Salt Mfg. Co.
Precision Chemical Pump Corp.
Proportioneers, Inc.

FERRIC CHLORIDE FEEDERS
(See Chemical Feed and Proportioning Equipment)

91R

FERRIC SULPHATE
Tennessee Corp.

FIBRE PIPE
(See Pipe, Fibre)

92R

FILTER AIDS
Johns-Manville
Proportioneers, Inc.

93R

FILTER ALUM
General Chemical Div., Allied Chemical & Dye Corp.
Koppers Co., Inc.

94R

FILTER EQUIPMENT
American Well Works
American Water Softener Co., Inc.
Bulkley, Dunton Processes, Inc.
Chemical Equipment Co.
Dorr-Oliver, Inc.
Everson Mfg. Co.
Filtration Equipment Corp.
Fischer & Porter Co.
General Filter Co.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Infilco, Inc.
Lakeside Engr. Corp.
F. B. Leopold Co., Inc.
Millipore Filter Corp.
Permutit Co.
Proportioneers, Inc.
Roberts Filter Mfg. Co.
Simplex Valve & Meter Co.
Smith & Loveless, Inc.
Stuart Corp.
Walker Process Equip., Inc.

95R

FILTER MEDIA
American Water Softener Co., Inc.
Anthracite Equipment Corp.
Bulkley, Dunton Processes, Inc.
The Carborundum Co.
Graver Water Conditioning Co.
Infilco, Inc.
Johns-Manville
Norton Co.
Proportioneers, Inc.
Stuart Corp.

96R

FILTER PLATES AND TUBES
American Well Works
The Carborundum Co.
Filtros, Inc.
Norton Co.

FILTER RATE CONTROLLERS AND GAGES
(See Rate Controllers)

97R

FILTER UNDERDRAINS, SEWAGE
The Carborundum Co.
Filtros, Inc.
Infilco, Inc.
Natco Corp.

98R

FILTER UNDERDRAINS, WATER
American Water Softener Co., Inc.
The Carborundum Co.
Filtration Equipment Corp.
Filtros, Inc.
General Filter Co.
Graver Water Conditioning Co.
Infilco, Inc.
F. B. Leopold Co., Inc.
National Clay Pipe Mfrs. Assn.
Roberts Filter Mfg. Co.
Stuart Corp.
Walker Process Equip., Inc.

99R

FILTERS VACUUM
Chicago Bridge & Iron Co.
Dorr-Oliver, Inc.
Komline-Sanderson Engineering Corp.
Morse Bros. Mach. Co.

100R

FITTINGS, PIPE, SOLDER TYPE
Crane Co.

101R

FITTINGS, TEES, ELLS, ETC.
American Cast Iron Pipe Co.
Cast Iron Pipe Research Assn.
James B. Clow & Sons
Continental Can Co.
Crane Co.
Dresser Mfg. Div.
Grinnell Company
M. & H. Valve & Fitting Co.
McWane Cast Iron Pipe Co.
Mueller Co.
United States Pipe & Foundry Co.
R. D. Wood Co.

FLASH MIXING EQUIPMENT
(See Mixers and Mixing Equipment)

FLEXIBLE JOINTS
(See Joints, Flexible Pipe)

102R

FLOATING COVERS (Digester)
Chicago Pump Co.
Infilco, Inc.
Pacific Flush Tank Co.
Walker Process Equip., Inc.

103R

FLOCCULATING EQUIPMENT
American Water Softener Co., Inc.
American Well Works
Bulkley, Dunton Processes, Inc.
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver, Inc.
General Filter Co.
Graver Water Conditioning Co.
Infilco, Inc.
Jeffrey Mfg. Co.
Lakeside Engr. Corp.
Link-Belt Co.
F. B. Leopold Co., Inc.
Permutit Co.
Reliance Chemicals Corp.
Smith & Loveless, Inc.
Stuart Corp.
Walker Process Equip., Inc.

FLOORING
(See Gratings)

FLOW RECORDERS
(See Rate of Flow Recorders)

FLOW REGULATORS
(See Rate of Flow Controllers)

104R

FLOW METERS
Bailey Meter Co.
Builders-Providence, Inc.
Chicago Pump Co.
Fischer & Porter Co.
Foxboro Co.
Infilco, Inc.
Leupold & Stevens Instruments, Inc.
Minneapolis-Honeywell Regulator Co.
Simplex Valve & Meter Co.
Sparling Meter Co., Inc.

105R

FLUMES, IRON AND STEEL
Bethlehem Steel Co.
Simplex Valve & Meter Co.

106R

FLUORIDATION CHEMICALS
Chemical Equipment Co.
Tennessee Corp.
John Wiley Jones Co.
General Chemical Div., Allied Chemical & Dye Corp.

107R

FLUORIDATION EQUIPMENT
Chemical Equipment Co.
Fischer & Porter Co.
Infilco, Inc.
Omega Machine Co.
Precision Chemical Pump Corp.
Proportioneers, Inc.
Wallace & Tiernan, Inc.

108R

FORMS AND GASKETS FOR PIPE JOINTS
Johns-Manville
Presstite Engineering Co.

109R

FURNACES (Melting, Pouring, Ladles, Pots, Etc.)
Hydraulic Development Corp.
Joseph G. Pollard Co., Inc.
Westinghouse Electric Corp.

110R

GAGES (Liquid Level, Pressure Recording)
Bailey Meter Co.
Builders-Providence, Inc.
Crane Co.
Fischer & Porter Co.
Foxboro Co.
Healy-Ruff Co.
Infilco, Inc.
Leupold & Stevens Instruments, Inc.
Minneapolis-Honeywell Regulator Co.
Pacific Flush Tank Co.
Simplex Valve & Meter Co.
Sparling Meter Co., Inc.

GARBAGE GRINDERS
(See Grinders)

111R

GAS DIFFUSERS
American Well Works
Chicago Pump Co.
Filtros, Inc.
General Filter Co.
Infilco, Inc.
Walker Process Equip., Inc.

GAS ENGINES
(See Engines, Gas)

112R

GAS HOLDERS
Bethlehem Steel Co.
Chicago Bridge & Iron Co.
Chicago Pump Co.
Dorr-Oliver, Inc.
Pacific Flush Tank Co.
Pittsburgh-Des Moines Steel Co.
Walker Process Equip., Inc.

113R

GAS INDICATOR AND DETECTORS
Bailey Meter Co.
General Electric Co.

114R

GATES, SHEAR
Chapman Valve Mfg. Co.
James B. Clow & Sons
Eddy Valve Co.
Filtration Equipment Corp.
Rodney Hunt Machine Co.
Iowa Valve Co.
Ludlow Valve Mfg. Co., Inc.
M. & H. Valve & Fitting Co.
Mueller Co.
Stuart Corp.
Washington Aluminum Co., Inc.

115R

GATES, SLUICE

Chapman Valve Mfg. Co.
Filer & Stowell Co.
Rodney Hunt Machine Co.
Iowa Valve Co.
Ludlow Valve Mfg. Co., Inc.
Morse Bros. Mach. Co.
Mueller Co.
Stuart Corp.
Washington Aluminum Co., Inc.

116R

GATE VALVE OPERATOR

Chapman Valve Mfg. Co.
Darling Valve & Mfg. Co.
Payne Dean & Co.
Eddy Valve Co.
Fischer & Porter Co.
Rodney Hunt Machine Co.
Infilco, Inc.
Iowa Valve Co.
Ludlow Valve Mfg. Co., Inc.

GATE VALVES

(See Valves, Gate)

117R

GEARS, SPEED REDUCING

De Laval Steam Turbine Co.
Link-Belt Co.
Westinghouse Electric Corp.
Worthington Corp.

118R

GEIGER COUNTERS

Detectron Corp.

GENERATOR SETS, GAS AND DIESEL ENGINES

(See Engine Generating Units)

119R

GENERATORS (Electric)

Allis-Chalmers Mfg. Co.
Electric Mach. Mfg. Co.
Fairbanks Morse & Co.
General Electric Co.
Homelite Corp.
Le Roi Div., Westinghouse Air Brake Co.
Westinghouse Electric Corp.
Worthington Corp.

120R

GOOSENECKS

Grinnell Company

121R

GRATINGS, FLOORING, TREADS

Atlas Mineral Products Co.
Irving Subway Grating Co., Inc.

122R

GREEN SAND

Chemical Equipment Co.
Infilco, Inc.
Lakeside Eng. Corp.
Permutit Co.

123R

GRINDERS, GARBAGE AND SCREENINGS

American Well Works
Chain Belt Co.
Dorr-Oliver, Inc.
General Electric Co.
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.
Walker Process Equip., Inc.

124R

GRIT CHAMBER EQUIPMENT AND GRIT WASHERS

American Well Works
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver, Inc.
Infilco, Inc.
Jeffrey Mfg. Co.
Link-Belt Co.
Stuart Corp.
Walker Process Equip., Inc.

125R

GROUND KEY STOPS

Ford Meter Box Co., Inc.
Weisbach Corp.

126R

GUNITING CONTRACTING

Cement Gun Co.
Chemical Fire & Rust Proofing Corp.

127R

HEATERS, DIGESTER

American Radiator & Standard Sanitary Corp.
Chicago Pump Co.
Dorr-Oliver, Inc.
Infilco, Inc.
Pacific Flush Tank Co.
Walker Process Equip., Inc.

HOSE, STEAM, AIR, WATER, SUCTION

United States Rubber Co.

128R

HYDRANTS (Fire)

James B. Clow & Sons
Darling Valve & Mfg. Co.
Eddy Valve Co.
Iowa Valve Co.
Ludlow Valve Mfg. Co., Inc.
M. & H. Valve & Fitting Co.
Mueller Co.
Rensselaer Valve
A. P. Smith Mfg. Co.
R. D. Wood Co.

HYDRANT PUMPS

(See Pumps, Hydrant)

HYDRAULICALLY OPERATED GATE VALVES

(See Valves, Gate)

HYDROGEN ION EQUIPMENT

(See pH Test Equipment)

HYPOCHLORITES (High Test)

(See Calcium Hypochlorite)

129R

HYPO-CHLORINATORS

American Water Softener Co., Inc.
Chemical Equipment Co.
Fischer & Porter Co.
Olin Mathieson Chemical Corp.
Omega Machine Co.
Precision Chemical Pump Corp.
Proportioneers, Inc.
Wallace & Tiernan, Inc.

130R

INCINERATORS (Sludge and Garbage)

Combustion Engineering, Inc.
Morse Boulger Destruction Co.
Nichols Eng. & Research Co.
Pittsburgh-Des Moines Steel Co.

131R

INDICATORS, LARGE DIAL ILLUMINATED

Bailey Meter Co.
Builders-Providence, Inc.
General Filter Co.
Infilco, Inc.
Leupold & Stevens Instruments, Inc.
Sparling Meter Co., Inc.

132R

INSECTICIDES

Diamond Alkali Co.
General Chemical Div., Allied Chemical & Dye Corp.
Koppers Company, Inc.
Pennsylvania Salt Mfg. Co.

133R

INSERTING SLEEVES, VALVE

James B. Clow & Sons
Iowa Valve Co.
Ludlow Valve Mfg. Co., Inc.
Mueller Co.
A. P. Smith Mfg. Co.

134R

INSULATION

Johns-Manville
J. W. Mortell Co.

IRON SULFATE

(See Ferric Sulfate, or Ferrous Sulfate)

135R

JOINTING COMPOUND AND MATERIALS

Atlas Mineral Products Co.
Grinnell Company
Hydraulic Development Corp.
Johns-Manville
Koppers Company, Inc.
Joseph G. Pollard Co., Inc.
Presstite Engineering Co.

136R

JOINTS, EXPANSION—PIPE

James B. Clow & Sons
Crane Co.
Dresser Mfg. Div.
Johns-Manville
United States Rubber Co.

137R

JOINTS, FLEXIBLE PIPE

James B. Clow & Sons
United States Pipe & Foundry Co.

138R

JOINTS, MECHANICAL FLEXIBLE

James B. Clow & Sons
Dresser Mfg. Div.
Grinnell Company
United States Pipe & Foundry Co.

139R

JUTE, BRAIDED AND TWISTED

Hydraulic Development Corp.
Joseph G. Pollard Co., Inc.

140R

LABORATORY APPARATUS REAGENTS AND EQUIPMENT

Arnold O. Beckman, Inc.
Bailey Meter Co.
Calgon, Inc.
Fischer & Porter Co.
General Chemical Div., Allied Chemical & Dye Corp.
General Laboratory Supply Co.
Hydraulic Development Corp.
Klett Mfg. Co.
Millipore Filter Corp.
Norton Co.
Phipps & Bird, Inc.
W. A. Taylor & Co.

LEAK LOCATING INSTRUMENTS

(See Water Leak Locating Instruments)

LINING, TANKS

(See Tanks, Lining)

LIQUID CHLORINE

(See Chlorine, Liquid)

141R

LOCATORS, BOX, PIPE AND VALVE

Detectron Corp.
Joseph G. Pollard Co., Inc.

142R

LUBRICANTS, VALVE

Rockwell Mfg. Co.

143R

MANHOLE FRAMES, COVERS

H. W. Clark Co.
James B. Clow & Sons
Irving Subway Grating Co., Inc.
A. Reed Wilson Co.

144R

MANOMETERS

Builders-Providence, Inc.
Fischer & Porter Co.
Infilco, Inc.
Simplex Valve & Meter Co.
Wallace & Tiernan, Inc.

145R

METEOROLOGICAL INSTRUMENTS

Leupold & Stevens Instruments, Inc.

146R

METER ACCESSORIES, BOXES, HOUSING SETTING, ETC.

Alabama Pipe Co.
H. W. Clark Co.
Darling Valve & Mfg. Co.
Ford Meter Box Co., Inc.
Iowa Valve Co.
Mueller Co.

147R

METER CLEANING (Equipment and Chemicals)

Bailey Meter Co.

148R

METER COUPLINGS, YOKES

Badger Meter Mfg. Co.
H. W. Clark Co.
Ford Meter Box Co., Inc.
Mueller Co.
Neptune Meter Co.

149R

METER REPAIR PARTS

Badger Meter Mfg. Co.
Hersey Mfg. Co.
Neptune Meter Co.
Worthington-Gamon Div., Worthington Corp.

150R

METERS, ELECTRIC

Bailey Meter Co.
General Electric Co.
Simplex Valve & Meter Co.
Westinghouse Electric Corp.
Minneapolis-Honeywell Regulator Co.

151R

METERS, FLOW TUBE

Bailey Meter Co.
Builders-Providence, Inc.
Simplex Valve & Meter Co.
Sparling Meter Co., Inc.

152R

METERS, GAS

Bailey Meter Co.
Builders-Providence, Inc.
Fischer & Porter Co.
Foxboro Co.
Minneapolis-Honeywell Regulator Co.
Rockwell Mfg. Co.
Roots-Connersville Blower

153R

METERS (Turbine Type)

Badger Meter Mfg. Co.
Fischer & Porter Co.
Hersey Mfg. Co.
Neptune Meter Co.
Rockwell Mfg. Co.
Worthington-Gamon Meter Div., Worthington Corp.

154R

METER TESTING EQUIPMENT

Badger Meter Mfg. Co.
Fischer & Porter Co.
Ford Meter Box Co., Inc.
Hersey Mfg. Co.
Neptune Meter Co.

155R

METERS, VENTURI

Bailey Meter Co.
Builders-Providence, Inc.
Foxboro Co.
Infilco, Inc.
Minneapolis-Honeywell Regulator Co.
Simplex Valve & Meter Co.

156R

METERS, WATER (Consumer)

Badger Meter Mfg. Co.
Buffalo Meter Co.
Builders-Providence, Inc.
Hersey Mfg. Co.
Neptune Meter Co.
Rockwell Mfg. Co.
Worthington-Gamon Meter Division, Worthington Corp.

157R

MIXERS AND MIXING EQUIPMENT

American Well Works
Chain Belt Co.
Dorr-Oliver, Inc.
Infilco, Inc.
Jeffrey Mfg. Co.
F. B. Leopold Co., Inc.
Stuart Corp.
Walker Process Equip., Inc.
Western Machinery Co.
Worthington Corp.

158R

MOTORS, ELECTRIC

Allis-Chalmers Mfg. Co.
Electric Mach. Mfg. Co.
Fairbanks Morse & Co.
General Electric Co.
U. S. Electrical Motors, Inc.
Westinghouse Electric Corp.
Worthington Corp.

159R

NOZZLES, FLOW

Bailey Meter Co.
Builders-Providence, Inc.
Foxboro Co.
Simplex Valve & Meter Co.

160R

NOZZLES, SPRAY (Water and Sewage)

Chain Belt Co.
Grinnell Company
Infilco, Inc.
Link-Belt Co.
Lakeside Engr. Corp.
Pacific Flush Tank Co.
Worthington Corp.
Yeomans Bros. Co.

161R

OPERATING TABLES (Filter)

American Water Softener Co., Inc.
Builders-Providence, Inc.
Filtration Equipment Corp.
Foxboro Co.
General Filter Co.
Infilco, Inc.
F. B. Leopold Co., Inc.
Permutit Co.
Roberts Filter Mfg. Co.
Walker Process Equip., Inc.

162R

ORIFICES

Bailey Meter Co.
Builders-Providence, Inc.
Fischer & Porter Co.
Foxboro Co.
General Filter Co.
Infilco, Inc.
Minneapolis-Honeywell Regulator Co.
Simplex Valve & Meter Co.
Worthington Corp.

163R

OZONE EQUIPMENT

Welsbach Corp.

164R

PACKING (Pumps and Valves)

Johns-Manville
United States Rubber Co.

165R

PAINT (Acid Resisting)

Amercoat Corp.
Atlas Mineral Products Co.
Hercules Powder Co., Inc.
Koppers Co., Inc.
J. W. Mortell Co.
Pennsylvania Salt Mfg. Co.
Pittsburgh Coke & Chemical Co.

166R

PENSTOCKS

Alco Products, Inc.
Bethlehem Steel Co.
Chicago Bridge & Iron Co.
R. D. Cole Mfg. Co.
Hammond Iron Works
Rodney Hunt Machine Co.
Nooter Corp.
Westinghouse Electric Corp.

167R

pH TEST EQUIPMENT

Allis-Chalmers Mfg. Co.
Bailey Meter Co.
General Laboratory Supply Co.
Infilco, Inc.
Permutit Co.
W. A. Taylor & Co.
Wallace & Tiernan, Inc.

168R

PHOTOELECTRIC COLORIMETERS

General Laboratory Supply Co.

169R

PIPE AND FITTINGS, LINED

American Cast Iron Pipe
American Hard Rubber Co.
Bethlehem Steel Co.
Cast Iron Pipe Research Assn.
Chemical Equipment Co.
James B. Clow & Sons
Crane Co.
Heresite & Chemical Co.
United States Pipe & Foundry Co.
United States Rubber Co.

170R

PIPE AND TANK COATINGS

Amercoat Corp.
Cement Gun Co., Inc.
Chemical Fire & Rust Proofing Corp.
Heresite & Chemical Co.
Johns-Manville
J. W. Mortell Co.
Pennsylvania Salt Mfg. Co.

171R

PIPE, ASBESTOS-CEMENT

Johns-Manville
Kensbey & Mattison Co.

172R

PIPE, CAST IRON

Alabama Pipe Co.
American Cast Iron Pipe
Cast Iron Pipe Research Assn.
James B. Clow & Sons
Combustion Engineering, Inc.
McWane Cast Iron Pipe Co.
National Supply Co.
United States Pipe & Foundry Co.
R. D. Wood Co.

173R

PIPE, CEMENT LINED

Alabama Pipe Co.
American Cast Iron Pipe
Cast Iron Pipe Research Assn.
James B. Clow & Sons
McWane Cast Iron Pipe Co.
United States Pipe & Foundry Co.
R. D. Wood Co.

174R

PIPE, CEMENT LINING OF

Ace Pipe Cleaning, Inc.
Centriline Corp.
James B. Clow & Sons
Pipe Linings, Inc.
Standard Dry Well Products, Inc.

175R

PIPE, CONCRETE, PRESSURE

American Concrete Pressure Pipe Assoc.
Price Bros. Co.

PIPE, COPPER, BRASS AND BRONZE

Mueller Co.

176R

PIPE, CULVERT

James B. Clow & Sons
Nooter Corp.
Price Bros. Co.

177R

PIPE CUTTING MACHINES

Ellis & Ford Mfg. Co., Inc.
Prescott Tool Co., Inc.
A. P. Smith Mfg. Co.
E. H. Wachs Co.

178R

PIPE ENAMELS, PROTECTIVE—COAL TAR

Alco Products, Inc.
Koppers Co., Inc.
J. W. Mortell Co.

PIPE FITTINGS

(See Fittings)

PIPE, HARD RUBBER LINES

(See Rubber Lined Pipe and Valves)

PIPE JOINT COMPOUNDS

(See Jointing Compounds)

179R

PIPE JOINT PACKING

Atlas Mineral Products Co.
Hydraulic Development Corp.
Johns-Manville
Presstite Engineering Co.

180R

PIPE JOINTS (Mechanical)

H. Y. Carson Co.
Cast Iron Pipe Research Assn.
James B. Clow & Sons
Grinnell Company
McWane Cast Iron Pipe Co.
United States Pipe & Foundry Co.
R. D. Wood Co.

181R

PIPE JOINT TOOLS

Hydraulic Development Corp.
Mueller Co.
Joseph G. Pollard Co., Inc.

182R

PIPE LOCATORS

Detectron Corp.
Joseph G. Pollard Co., Inc.
Filtration Equipment Corp.

183R

PIPE, PLASTIC

American Hard Rubber Co.
Atlas Mineral Products Co.
Chemical Equipment Co.
Continental Can Co.
Crane Co.
United States Rubber Co.
Westinghouse Electric Corp.
Yardley Plastic Co.

184R

PIPE, SEWER

Bethlehem Steel Co.
James B. Clow & Sons
Johns-Manville
Kensbey & Mattison Co.
Nateo Corp.
National Clay Pipe Mfrs. Assn.
National Supply Co.
Price Bros. Co.
United States Pipe & Foundry Co.

185R

PIPE, STEEL (All Types)

Alco Products, Inc.
Bethlehem Steel Co.
National Supply Co.

186R

PIPE TAPPING MACHINES

Mueller Co.
A. P. Smith Mfg. Co.
Welsbach Corp.

187R

PIPE TEST PLUGS

James B. Clow & Sons
Eddy Valve Co.
Flexible Sales Corp.
Joseph G. Pollard Co., Inc.
A. P. Smith Mfg. Co.

188R

PIPE THAWING, ELECTRICAL, STEAM, FLAME

Joseph G. Pollard Co., Inc.

189R

PIPE TOOLS (Asbestos, Cement)

E. H. Wachs Co.

190R

PIPE TOOLS (Cutters, Extractors, Threaders, Wrenches, Etc.)

Flexible Sales Corp.
E. H. Wachs Co.

PIPE, VITRIFIED CLAY

(See Vitrified Clay Pipe and Products)

191R

PIPE WRAPPING

Chemical Fire & Rust Proofing Corp.
Johns-Manville
J. W. Mortell Co.
Pipe Linings, Inc.

192R

PIPE, WROUGHT IRON

A. M. Byers Co.

193R

PITOT TUBES

Foxboro Co.
Simplex Valve & Meter Co.

PLASTIC PIPE AND TUBING

(See Pipe Plastic)

PNEUMATIC CONVEYORS

(See Conveyors and Conveying Equipment)

194R

POROUS TUBES AND PLATES

American Well Works
The Carborundum Co.
Filtros, Inc.
Walker Process Equip., Inc.

195R

POWER TAKE-OFF (Truck Type)

Payne Dean & Co.

PRESSURE REGULATORS

(See Regulators, Pressure)

196R

PRESTRESSED CONCRETE TANKS

Cement Gun Co., Inc.

PROPORTIONING EQUIPMENT

(See Chemical Feed and Proportioning Equipment)

197R

PUMPING CONTROLS

Builders-Providence, Inc.
Chicago Pump Co.
Fischer & Porter Co.
General Electric Co.
Healy-Ruff Co.
Smith & Loveless, Inc.

198R

PUMP PRIMERS

Chicago Pump Co.
Smith & Loveless, Inc.

199R

PUMPS, ACID-HANDLING

Allis-Chalmer Mfg. Co.
American Hard Rubber Co.
Aurora Pump Div., N. Y. Air Brake Co.
De Laval Steam Turbine Co.
Dorr-Oliver, Inc.
Fischer & Porter Co.
Johnston Pump Co.
Komline-Sanderson Engineering Corp.
Peerless Pump Div.
Precision Chemical Pump Corp.
Weinman Pump Mfg. Co.
Worthington Corp.
Yeomans Bros. Co.

PUMPS, CELLAR DRAINER
(See Pumps, Sump)

200R
PUMPS, CENTRIFUGAL
Allis-Chalmers Mfg. Co.
American Well Works
Aurora Pump Div., N. Y. Air Brake Co.
Chain Belt Co.
Chicago Pump Co.
De Laval Steam Turbine Co.
Dorr-Oliver, Inc.
Economy Pump, Inc.
Fairbanks Morse & Co.
Homelite Corp.
Peerless Pump Div.
Weil Pump Co.
Weinman Pump Mfg. Co.
Western Machinery Co.
Worthington Corp.
Yeomans Bros. Co.

201R
PUMPS, DEEP WELL
American Well Works
Aurora Pump Div., N. Y. Air Brake Co.
Byron Jackson Co.
Fairbanks Morse & Co.
Johnston Pump Co.
Layne & Bowler, Inc.
Peerless Pump Div.
Worthington Corp.

202R
PUMPS, DIAPHRAGM
Chain Belt Co.
Dorr-Oliver, Inc.
Fischer & Porter Co.
Komline-Sanderson Engineering Corp.
Morse Bros. Machinery Co.
Joseph G. Pollard Co., Inc.
Precision Chemical Pump Corp.
Proportioneers, Inc.
Western Machinery Co.

214R
PUMPS, DRAINAGE
(See Pumps, Sewage and Drainage)

203R
PUMPS, HYDRANT
Ellis & Ford Mfg. Co., Inc.
Joseph G. Pollard Co., Inc.

204R
PUMPS, HYDRAULIC (Pressure Boosting)
Weinman Pump Mfg. Co.
Worthington Corp.

205R
PUMPS, PORTABLE
Chain Belt Co.
Fairbanks Morse & Co.
Homelite Corp.
Peerless Pump Div.
Worthington Corp.

206R
PUMPS, ROTARY
De Laval Steam Turbine Co.
Fairbanks Morse & Co.
Roots-Connersville Blower
Worthington Corp.

207R
PUMPS, SELF-PRIMING
Aurora Pump Div., N. Y. Air Brake Co.
Chain Belt Co.
De Laval Steam Turbine Co.
Fairbanks Morse & Co.
Johnston Pump Co.
Peerless Pump Div.
Roots-Connersville Blower
Worthington Corp.

208R
PUMPS, SEWAGE AND DRAINAGE
Allis-Chalmers Mfg. Co.
American Well Works
Aurora Pump Div., N. Y. Air Brake Co.
Chicago Pump Co.
Economy Pump, Inc.
Fairbanks Morse & Co.
Layne & Bowler, Inc.
Peerless Pump Div.
Weil Pump Co.
Weinman Pump Mfg. Co.
Western Machinery Co.
Worthington Corp.
Yeomans Bros. Co.

209R
PUMPS, SLUDGE
Allis-Chalmers Mfg. Co.
American Well Works
Aurora Pump Div., N. Y. Air Brake Co.
Chicago Pump Co.
Dorr-Oliver, Inc.
Economy Pump, Inc.
Fairbanks Morse & Co.
Komline-Sanderson Engineering Corp.
Lakeside Engr. Corp.
Peerless Pump Div.
Walker Process Equip., Inc.
Western Machinery Co.
Worthington Corp.
Yeomans Bros. Co.

210R
PUMPS, SUMP (AND CELLAR DRAINER)
Aurora Pump Div., N. Y. Air Brake Co.
Byron Jackson Co.
Chicago Pump Co.
Economy Pumps, Inc.
Fairbanks Morse & Co.
Johnston Pump Co.
Peerless Pump Div.
Weil Pump Co.
Weinman Pump Mfg. Co.
Western Machinery Co.
Worthington Corp.
Yeomans Bros. Co.

211R
PUMPS, TURBINE
American Well Works
Aurora Pump Div., N. Y. Air Brake Co.
Fairbanks Morse & Co.
Johnston Pump Co.
Layne & Bowler, Inc.
Peerless Pump Div.
Worthington Corp.

212R
PUMPS, VACUUM
Allis-Chalmers Mfg. Co.
Chicago Pump Co.
Dorr-Oliver, Inc.
General Laboratory Supply Co.
Roots-Connersville Blower
Worthington Corp.
Yeomans Bros. Co.

RAIN GAGES
(See Meteorological Instrument)

213R
RATE OF FLOW CONTROLLERS
Badger Meter Mfg. Co.
Bailey Meter Co.
Builders-Providence, Inc.
Bulkley, Dunton Processes, Inc.
Fischer & Porter Co.
Foxboro Co.
General Filter Co.
Infilco, Inc.
Minneapolis-Honeywell Regulator Co.
Simplex Valve & Meter Co.
Sparling Meter Co., Inc.

RATE OF FLOW RECORDERS
Badger Meter Mfg. Co.
Bailey Meter Co.
Builders-Providence, Inc.
Fischer & Porter Co.
Foxboro Co.
General Filter Co.
Infilco, Inc.
Leupold & Stevens Instruments, Inc.
Minneapolis-Honeywell Regulator Co.
Simplex Valve & Meter Co.
Sparling Meter Co., Inc.

RECARBONATORS
(See Carbonators)

215R
REFRACTORIES
The Carborundum Co.
Johns-Manville
Norton Co.

216R
REGULATORS, PRESSURE (Water and Gas)
American Radiator & Standard Sanitary Corp.
Bailey Meter Co.
Fischer & Porter Co.
Foster Engineering Co.
Rockwell Mfg. Co.

RESERVOIRS, STEEL
(See Tanks and Standpipes)

217R
RESIDUAL CHLORINE CONTROLLERS
General Laboratory Supply Co.
W. A. Taylor & Co.
Wallace & Tiernan, Inc.

218R
RESIDUAL CHLORINE TEST APPARATUS
W. A. Taylor & Co.
Wallace & Tiernan, Inc.

219R
ROOF COATINGS
Johns-Manville
Koppers Co., Inc.
Prestite Engineering Co.

220R
RUBBER LINED PIPES AND VALVES
American Hard Rubber Co.
Darling Valve & Mfg. Co.
Grinnell Company
Heresite & Chemical Co.
United States Rubber Co.

221R
RUBBER PACKING GASKETS
Hamilton Kent Mfg. Co.
Johns-Manville
United States Rubber Co.

222R
RUST PREVENTION (Water Treatment)
Calgon, Inc.
Graver Water Conditioning Co.
Philadelphia Quartz Co.

223R
SADDLES, PIPE
James B. Clow & Sons
Dresser Mfg. Div.
Mueller Co.
Price Bros. Co.

224R
SAMPLERS AND SAMPLING TABLES
Builders-Providence, Inc.
General Laboratory Supply Co.
Infilco, Inc.
F. B. Leopold Co., Inc.
Walker Process Equip., Inc.

225R
SAND EXPANSION INDICATORS
Builders-Providence, Inc.
Infilco, Inc.
Simplex Valve & Meter Co.

226R
SCALES, SLUDGE CONVEYOR
Builders-Providence, Inc.
Fairbanks Morse & Co.

SCREENING AND COMMINUTING
(See Comminuting Devices)

SCREENINGS GRINDERS
(See Grinders)

227R
SCREENS, INTAKE
Chain Belt Co.
Rodney Hunt Machine Co.
Jeffrey Mfg. Co.
Link-Belt Co.

228R
SCREENS, INTAKE (Electric)
Electric Fish Screen Co.

229R
SCREENS, SEWAGE
American Well Works
Dorr-Oliver, Inc.
Infilco, Inc.
Jeffrey Mfg. Co.
Link-Belt Co.
Walker Process Equip., Inc.

230R
SCREENS, VIBRATING
Allis-Chalmers Mfg. Co.
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.
Link-Belt Co.

231R
SCREEN, WATER WELL
Cook Well Strainer Co.

SCUM REMOVERS
(See Clarifiers)

232R
SEGMENT BLOCKS AND PIPE LINER PLATES (Vitrified)
Nateo Corp.
National Clay Pipe Mfrs. Assn.

233R
SERVICE BOXES (Water)
H. W. Clark Co.
James B. Clow & Sons
Ford Meter Box Co., Inc.
Mueller Co.

SEWAGE EJECTORS
(See Ejectors, Pneumatic)

234R
SEWAGE SAMPLERS
Chicago Pump Co.
Dezurik Shower Co.
General Laboratory Supply Co.
Infilco, Inc.
Lakeside Engr. Corp.
Proportioneers, Inc.
Walker Process Equip., Inc.

SEWAGE SLUDGE DRYERS
(See Drying Systems, Sludge)

SEWAGE SLUDGE INCINERATORS
(See Incinerators)

235R
SEWER CLEANING EQUIPMENT AND SERVICE
Ace Pipe Cleaning, Inc.
Flexible Pipe Cleaning Co.
Flexible Sales Corp.
National Power Rodding Corp.

SEWER PIPE
(See Pipe, Sewer)

236R
SEWER PIPE JOINTS (and Jointing Compounds)
Hydraulic Development Corp.
Johns-Manville
National Clay Pipe Mfrs. Assn.
Prestite Engineering Co.

237R
SEWER RODS
Flexible Sales Corp.

238R
SIPHONS (Sewage Dosing)
American Well Works
Infilco, Inc.
Pacific Flush Tank Co.
Price Bros. Co.

239R
SLEEVES, PIPE REPAIR
James B. Clow & Sons
Dresser Mfg. Div.
Eddy Valve Co.
M. & H. Valve & Fittings Co.
Mueller Co.
A. P. Smith Mfg. Co.

240R
SLEEVES, TAPPING (Valve)
James B. Clow & Sons
Corey Mfg. Co.
Darling Valve & Mfg. Co.
Eddy Valve Co.
M. & H. Valve & Fittings Co.
Mueller Co.
Rensselaer Valve Co.
A. P. Smith Mfg. Co.

241R
SLUDGE COLLECTORS
American Well Works
Bulkley, Dunton Processes, Inc.
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver, Inc.
General Filter Co.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Jeffrey Mfg. Co.
Lakeside Engr. Corp.
Link-Belt Co.
Walker Process Equip., Inc.

242R
SLUDGE DISINTEGRATORS
Dorr-Oliver, Inc.
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.
Royer Foundry & Machine Co.

SLUDGE DRYERS
(See Drying Systems)

SLUDGE EJECTORS
(See Ejectors, Pneumatic)

SLUDGE GAS ENGINES
(See Engines, Sludge Gas)

SLUDGE INCINERATORS
(See Incinerators)

SLUDGE PUMPS
(See Pumps, Sludge)

243R
SLUDGE SAMPLERS
Infilco, Inc.
Jeffrey Mfg. Co.
Walker Process Equip., Inc.

244R
SLUDGE VALVES (Telescopic)
ACF Industries, Inc.
American Well Works
Dezurik Shower Co.
Roberts Filter Mfg. Co.
Rockwell Mfg. Co.
Walker Process Equip., Inc.

245R
SODA ASH
Diamond Alkali Co.
Niagara Alkali Co.

246R
SODIUM BISULPHITE
General Chemical Div., Allied Chemical & Dye Corp.

247R
SODIUM HYPOCHLORITE
John Wiley Jones Co.
Pennsylvania Salt Mfg. Co.
Wallace & Tiernan, Inc.

248R
SODIUM PHOSPHATES (Glassy)
Calgon, Inc.
General Chemical Div., Allied Chemical & Dye Corp.
Pennsylvania Salt Mfg. Co.

249R
SODIUM SILICATE
Diamond Alkali Co.
General Chemical Div., Allied Chemical & Dye Corp.
Philadelphia Quartz Co.

SOFTENERS
(See Water Softening Equipment)

250R
SPEED REDUCERS, TRANSMISSION
Allis-Chalmers Mfg. Co.
De Laval Steam Turbine Co.
Link-Belt Co.

SPRINKLING FILTER EQUIPMENT
(See Trickling Filter Equipment)

SPRINKLING FILTER UNDERDRAINS
(See Filter Underdrains, Sewage)

251R
STACKS
Bethlehem Steel Co.
R. D. Cole Mfg. Co.
Pittsburgh-Des Moines Steel Co.

STANDPIPES
(See Tanks and Standpipes)

252R
STIRRERS (Laboratory)
General Laboratory Supply Co.
Infilco, Inc.
Phipps & Bird, Inc.

253R
STOKERS
Combustion Engineering, Inc.
Fairbanks Morse & Co.

254R
STRAINERS—SUCTION
Blackburn-Smith Mfg. Co., Inc.
Layne & Bowler, Inc.
S. Morgan Smith Co.

SULPHATE OF ALUMINA
(See Filter Alum)

255R
SULPHUR DIOXIDE (Liquid)
General Chemical Div., Allied Chemical & Dye Corp.
Tennessee Corp.

256R
SWITCHBOARD AND SWITCH GEAR
Allis-Chalmers Mfg. Co.
Blackburn-Smith Mfg. Co., Inc.
Electric Mach. Mfg. Co.
General Electric Co.
Westinghouse Electric Corp.

257R
TANK LININGS
Amercoat Corp.
Atlas Mineral Products Co.
Cement Gun Co., Inc.
Chemical Equipment Co.
Chemical Fire and Rust Proofing Corp.
General Filter Co.
Natco Corp.
United States Rubber Co.

258R
TANK MAINTENANCE AND REPAIR
Cement Gun Co., Inc.
Murray Brothers
Nooter Corp.
Speelmon Elevated Tank Service

259R
TANKS AND STANDPIPES
Bethlehem Steel Co.
Chicago Bridge & Iron Co.
R. D. Cole Mfg. Co.
Graver Water Conditioning Co.
Hammond Iron Works
Nooter Corp.
Pittsburgh-Des Moines Steel Co.

260R
TANKS, RUBBER LINED
American Hard Rubber Co.
Atlas Mineral Products Co.
Chemical Equipment Co.
Chicago Bridge & Iron Co.
R. D. Cole Mfg. Co.
Graver Water Conditioning Co.
Hammond Iron Works
Heresite & Chemical Co.
United States Rubber Co.

261R
TAPPING MACHINES
Mueller Co.
A. P. Smith Mfg. Co.
Welsbach Corp.

262R
TASTE AND ODOR REMOVAL CHEMICALS
General Chemical Div., Allied Chemical & Dye Corp.
Infilco, Inc.
John Wiley Jones Co.
Wallace & Tiernan, Inc.

263R
TESTERS (Water Meter)
Ford Meter Box Co., Inc.
Hersey Mfg. Co.

264R
THICKENERS (Sludge)
American Well Works
Chain Belt Co.
Dorr-Oliver, Inc.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Lakeside Engr. Corp.
Link-Belt Co.
Tennessee Corp.
Walker Process Equip., Inc.
Western Machinery Co.

TOOLS, PIPE
(See Pipe Tools)

265R
TOOLS, PNEUMATIC
Worthington Corp.

266R
TRACTORS, BULLDOZERS, ETC.
Allis-Chalmers Mfg. Co.
Oliver Corp.

267R
TRANSFORMERS, ELECTRIC
Allis-Chalmers Mfg. Co.
General Electric Co.
Westinghouse Electric Corp.

268R
TRAPS, DRIP, FLAME, SEDIMENT, STEAM
Crane Co.
General Electric Co.
Neptune Meter Co.
Pacific Flush Tank Co.

269R
TRENCHING EQUIPMENT
Bucyrus-Erie

270R
TRICKLING FILTER EQUIPMENT
American Well Works
Bulkley, Dunton Processes, Inc.
Dorr-Oliver, Inc.
General Filter Co.
Infilco, Inc.
Lakeside Engr. Corp.
Nateo Corp.
Pacific Flush Tank Co.
Smith & Loveless, Inc.
Walker Process Equip., Inc.
Yeomans Bros. Co.

TRICKLING FILTER UNDERDRAINS
(See Filter Underdrains)

271R
TURBIDIMETERS
General Electric Co.
Infilco, Inc.
Klett Mfg. Co.

272R
TURBINES, HYDRAULIC
Allis-Chalmers Mfg. Co.
Rodney Hunt Machine Co.

273R
TURBINES, STEAM
Allis-Chalmers Mfg. Co.
De Laval Steam Turbine Co.
General Electric Co.
Westinghouse Electric Corp.
Worthington Corp.

274R
VACUUM FILTERS
Chicago Bridge & Iron Co.
Dorr-Oliver, Inc.
Komline-Sanderson Engineering Corp.

275R
VALVE BOXES
Alabama Pipe Co.
James B. Clow & Sons
Dezurik Shower Co.
Eddy Valve Co.
Filtration Equipment Corp.
Ford Meter Box Co., Inc.
Iowa Valve Co.
Ludlow Valve Mfg. Co., Inc.
Mueller Co.
Rensselaer Valve Co.
A. P. Smith Mfg. Co.
R. D. Wood Co.

276R
VALVE BOX LOCATORS
Joseph G. Pollard Co., Inc.

277R
VALVE INSERTING MACHINES
Mueller Co.
A. P. Smith Mfg. Co.

VALVE OPERATOR
(See Gate Valve Operator)

278R
VALVE VAULT COVERS
E. H. Wachs Co.

279R
VALVES, AIR RELEASE AND VACUUM BREAKING
Darling Valve & Mfg. Co.
Eddy Valve Co.
Foster Engineering Co.
Ludlow Valve Mfg. Co., Inc.
Rensselaer Valve Co.
Simplex Valve & Meter Co.

280R
VALVES, ALTITUDE
Chapman Valve Mfg. Co.
Foster Engineering Co.
Henry Pratt Co.
S. Morgan Smith Co.

302R
VENTURI TUBES
Bailey Meter Co.
Builders-Providence, Inc.
Foxboro Co.
Infilco, Inc.
Simplex Valve & Meter Co.

303R

VIBRATING SCREENS (Liquid)

Link-Belt Co.

304R

VITRIFIED CLAY PIPE AND PRODUCTS

Natco Corp.
National Clay Pipe Mfrs. Assn.

305R

WASTE GAS BURNERS

Pacific Flush Tank Co.

WATER ANALYSIS EQUIPMENT AND REAGENTS

(See Laboratory Apparatus & Reagents)

306R

WATER LEAK, LOCATING INSTRUMENTS

Detectron Corp.
Joseph G. Pollard Co., Inc.

307R

WATER LEVEL CONTROL

Bailey Meter Co.
Builders-Providence, Inc.
Fischer & Porter Co.
Foster Engineering Co.
Foxboro Co.
General Electric Co.
Healy-Ruff Co.
Infilco, Inc.
Leupold & Stevens Instruments, Inc.
Minneapolis-Honeywell Regulator Co.
Simplex Valve & Meter Co.
Smith & Loveless, Inc.
Sparling Meter Co., Inc.

308R

WATER LEVEL RECORDERS

Bailey Meter Co.
Builders-Providence, Inc.
Fischer & Porter Co.
Foster Engineering Co.
Foxboro Co.
General Electric Co.
Infilco, Inc.
Leupold & Stevens Instruments, Inc.
Minneapolis-Honeywell Regulator Co.
Simplex Valve & Meter Co.
Sparling Meter Co., Inc.

309R

WATER MAIN CLEANING

Ace Pipe Cleaning, Inc.
Flexible Pipe Cleaning Co.
Flexible Sales Corp.
National Water Main Cleaning Co.
Robinson Pipe Cleaner Co.

310R

WATERPROOFING PAINTS, COMPOUNDS AND MATERIALS

Atlas Mineral Products Co.
Johns-Manville
Koppers Co., Inc.
J. W. Mortell Co.
Pittsburgh Paint & Chemical Co.
Pressitite Engineering Co.
Standard Dry Wall Products, Inc.

WATER SOFTENING CHEMICALS AND COMPOUNDS

(See Individual Chemicals for Water Purification and Softening)

311R

WATER SOFTENING EQUIPMENT

Allis-Chalmers Mfg. Co.
American Water Softener Co., Inc.
American Well Works
Chemical Equipment Co.
Dorr-Oliver, Inc.
General Filter Co.
General Laboratory Supply Co.
Graver Water Conditioning Co.
Infilco, Inc.
Lakeside Engr. Corp.
Layne & Bowler, Inc.
Permutit Co.
Roberts Filter Mfg. Co.
Stuart Corp.
Walker Process Equip., Inc.

WATER SUPPLY CONTRACTORS

(See Contractors)

312R

WATER TREATMENT FOR SCALE AND CORROSION

Allis-Chalmers Mfg. Co.
American Water Softener Co., Inc.
American Well Works
Calgon, Inc.
Chemical Equipment Co.
General Filter Co.
Graver Water Conditioning Co.
Infilco, Inc.
John Wiley Jones Co.
Lakeside Engr. Corp.
Permutit Co.
Precision Chemical Pump Corp.
Proportioneers, Inc.

313R

WEED KILLERS

Diamond Alkali Co.
General Chemical Div., Allied Chemical & Dye Corp.
Koppers Company, Inc.

314R

WELL CLEANING CHEMICALS

Calgon, Inc.

315R

WELLS, COMPLETE

Layne & Bowler, Inc.
Ranney Method Water Supplies, Inc.

WRAPPING, PIPE

(See Pipe, Wrapping)

316R

ZEOLITE AND ZEOLITE SOFTENERS

Allis-Chalmers Mfg. Co.
American Water Softener Co., Inc.
Chemical Equipment Co.
General Filter Co.
Graver Water Conditioning Co.
Infilco, Inc.
Lakeside Engr. Corp.
Permutit Co.
Roberts Filter Mfg. Co.

281R

VALVES, BUTTERFLY

Allis-Chalmers Mfg. Co.
Builders-Providence, Inc.
Chapman Valve Mfg. Co.
Foster Engineering Co.
Foxboro Co.
Ludlow Valve Mfg. Co., Inc.
Minneapolis-Honeywell Regulator Co.
Henry Pratt Co.
S. Morgan Smith Co.
Westinghouse Electric Corp.
Worthington Corp.

282R

VALVES, CHECK

ACF Industries, Inc.
Chapman Valve Mfg. Co.
James B. Clow & Sons
Crane Co.
Darling Valve & Mfg. Co.
Eddy Valve Co.
Grinnell Company
Hersey Mfg. Co.
Iowa Valve Co.
Jeffrey Mfg. Co.
M. & H. Valve & Fittings Co.
Mueller Co.
Rensselaer Valve Co.
A. P. Smith Mfg. Co.
S. Morgan Smith Co.

283R

VALVES, CHLORINE

Chemical Equipment Co.
Crane Co.
Fischer & Porter Co.

284R

VALVES, CONE

Chapman Valve Mfg. Co.
S. Morgan Smith Co.

285R

VALVES, DIAPHRAGM

Bailey Meter Co.
Crane Co.
Darling Valve & Mfg. Co.
Fischer & Porter Co.
Foster Engineering Co.
Foxboro Co.
Grinnell Company
Minneapolis-Honeywell Regulator Co.
S. Morgan Smith Co.

VALVES, ELECTRICALLY OPERATED

(See Valves, Motor Operated)

286R

VALVES, FLAP

Chapman Valve Mfg. Co.
James B. Clow & Sons
Rodney Hunt Machine Co.
Iowa Valve Co.
Ludlow Valve Mfg. Co., Inc.
M. & H. Valve & Fittings Co.
Mueller Co.

287R

VALVES, FLOAT

Foster Engineering Co.
Lakeside Engr. Corp.
Ludlow Valve Mfg. Co., Inc.
Henry Pratt Co.

288R

VALVES, FOOT

Chapman Valve Mfg. Co.
Crane Co.
Eddy Valve Co.
Rodney Hunt Machine Co.
Ludlow Valve Mfg. Co., Inc.

289R

VALVES, FOUR WAY

Crane Co.
Dezurik Shower Co.
Homestead Valve Mfg. Co.
Infilco, Inc.
F. B. Leopold Co., Inc.
Ludlow Valve Mfg. Co., Inc.
Rockwell Mfg. Co.

290R

VALVES, GATE

Chapman Valve Mfg. Co.
James B. Clow & Sons
Crane Co.
Darling Valve & Mfg. Co.
Eddy Valve Co.
Filer & Stowell Co.
Fischer & Porter Co.
Rodney Hunt Machine Co.
Iowa Valve Co.
Jeffrey Mfg. Co.
Ludlow Valve Mfg. Co., Inc.
M. & H. Valve & Fittings Co.
Mueller Co.
Rensselaer Valve Co.
A. P. Smith Mfg. Co.
Westinghouse Electric Corp.
R. D. Wood Co.
Worthington Corp.

291R

VALVES, HYDRAULIC CYLINDER OPERATED

Builders-Providence, Inc.
Chapman Valve Mfg. Co.
James B. Clow & Sons
Crane Co.
Darling Valve & Mfg. Co.
Dezurik Shower Co.
Eddy Valve Co.
Filer & Stowell Co.
Grinnell Company
Homestead Valve Mfg. Co.
Rodney Hunt Machine Co.
Iowa Valve Co.
Ludlow Valve Mfg. Co., Inc.
M. & H. Valve & Fittings Co.
Henry Pratt Co.
Rensselaer Valve Co.
Rockwell Mfg. Co.
A. P. Smith Mfg. Co.
S. Morgan Smith Co.

292R

VALVES, LUBRICATED PLUG

ACF Industries, Inc.
Homestead Valve Mfg. Co.
Rockwell Mfg. Co.

293R

VALVES, MECHANICAL JOINT

James B. Clow & Sons
Crane Co.
Darling Valve & Mfg. Co.
Dezurik Shower Co.
Eddy Valve Co.
Iowa Valve Co.
Ludlow Valve Mfg. Co., Inc.
M. & H. Valve & Fittings Co.
Mueller Co.
Henry Pratt Co.
Rensselaer Valve Co.
Rockwell Mfg. Co.
A. P. Smith Mfg. Co.

294R

VALVES, MOTOR OPERATED

ACF Industries, Inc.
Chapman Valve Mfg. Co.
James B. Clow & Sons
Crane Co.
Darling Valve & Mfg. Co.
Dezurik Shower Co.
Eddy Valve Co.
Filer & Stowell Co.
Fischer & Porter Co.
Homestead Valve Mfg. Co.
Rodney Hunt Machine Co.
Infilco, Inc.
Iowa Valve Co.
Ludlow Valve Mfg. Co., Inc.
M. & H. Valve & Fittings Co.
Minneapolis-Honeywell Regulator Co.
Mueller Co.
Payne Dean & Co.
Permutit Co.
Henry Pratt Co.
Rensselaer Valve Co.
Rockwell Mfg. Co.
A. P. Smith Mfg. Co.
S. Morgan Smith Co.
Westinghouse Electric Corp.

295R

VALVES, MUD AND PLUG

ACF Industries, Inc.
Chapman Valve Mfg. Co.
James B. Clow & Sons
Dezurik Shower Co.
Eddy Valve Co.
Filer & Stowell Co.
Homestead Valve Mfg. Co.
Rodney Hunt Machine Co.
Iowa Valve Co.
Ludlow Valve Mfg. Co., Inc.
M. & H. Valve & Fittings Co.
Mueller Co.
Roberts Filter Mfg. Co.

296R

VALVES, PRESSURE REDUCING

Bailey Meter Co.
Crane Co.
Fischer & Porter Co.
Foster Engineering Co.
Mueller Co.
S. Morgan Smith Co.

297R

VALVES, RELIEF

James B. Clow & Sons
Crane Co.
Darling Valve & Mfg. Co.
Foster Engineering Co.
Mueller Co.
Simplex Valve & Meter Co.
S. Morgan Smith Co.

298R

VALVES (Rubber, Plastic, Glass or Lead)

American Hard Rubber Co.
Atlas Mineral Products Co.
Chemical Equipment Co.
Crane Co.
Darling Valve & Mfg. Co.
Dezurik Shower Co.
Grinnell Company
S. Morgan Smith Co.

299R

VALVES, SPECIAL, AUTOMATIC (Including Remote Control)

ACF Industries, Inc.
American Water Softener Co., Inc.
Bailey Meter Co.
Darling Valve & Mfg. Co.
Eddy Valve Co.
Fischer & Porter Co.
Foster Engineering Co.
Foxboro Co.
Grinnell Company
Rodney Hunt Machine Co.
Infilco, Inc.
Minneapolis-Honeywell Regulator Co.
Permutit Co.
Rockwell Mfg. Co.
S. Morgan Smith Co.
Walker Process Equip., Inc.

300R

VALVES, WATER METER SPECIAL

Ford Meter Box Co., Inc.
Hersey Mfg. Co.
Mueller Co.
S. Morgan Smith Co.
Sparling Meter Co., Inc.

301R

VARIABLE SPEED TRANSMISSIONS

Allis-Chalmers Mfg. Co.
Electric Machinery Mfg. Co.
U. S. Electrical Motors, Inc.
Worthington Corp.

DIRECTORY OF MANUFACTURERS

Listed in Classified Index of Products

A

ACF Industries, Inc.
30 Church St.
New York 8, N. Y.

Airkem, Inc.
241 S. 44th St.
New York 17, N. Y.

Alabama Pipe Co.
P. O. Box 791
Anniston, Ala.

Allis-Chalmers Mfg. Co.
1192 S. 70th St.
Milwaukee 1, Wis.

Amercoat Corporation
4809 Firestone Blvd.
South Gate, Calif.

American Cast Iron Pipe Co.
Birmingham 2, Ala.

Amer. Concrete Pipe Assn.
228 N. LaSalle St.
Chicago 1, Ill.

American Concrete Pressure Pipe Assoc.
228 N. LaSalle St.
Chicago 1, Ill.

American Hard Rubber Co.
93 Worth St.
New York 13, N. Y.

Alco Products Inc.
Schenectady 5, N. Y.

American Radiator & Standard Sanitary Corp.
Bessemer Building
Pittsburgh 22, Pa.

American Water Softener Company
Lehigh and 4th Streets
Philadelphia, Pa.

American Well Works Co.
100 N. Broadway
Aurora, Ill.

Anthracite Equipment Co.
Anthracite Institute Bldg.
Wilkes Barre, Pa.

Atlas Mineral Products Co.
42 Walnut St.
Mertztown, Pa.

Aurora Pump Co.
68 Loucks St.
Aurora, Ill.

B

Badger Meter Mfg. Co.
Milwaukee 45, Wis.

Bailey Meter Co.
1072 Ivanhoe Road
Cleveland, Ohio

A. O. Beckman Co.
1020 Mission St.
South Pasadena 19, Calif.

Ernest Bernard Elec. Co.
10335 S. Morgan St.
Chicago 43, Ill.

Bethlehem Steel Co.
E. 3rd St.
Bethlehem, Pa.

Blackburn-Smith Manufacturing Co.
55 Garden St.
Hoboken, N. J.

Bucyrus-Erie Co.
Publicity Dept.
S. Milwaukee, Wis.

Buffalo Meter Co.
2914 Main St.
Buffalo 14, N. Y.

Builders-Providence, Inc.
345 Harris Ave.
Providence, R. I.

Bulkley, Dunton Processes, Inc.
295 Madison Ave.
New York 17, N. Y.

A. M. Byers Co.
Clark Bldg.
Pittsburgh, Pa.

Byron Jackson Co.
Box 2017, Terminal Annex
Los Angeles 54, Calif.

C

Calgon, Inc.
Hagan Bldg.
Pittsburgh, Pa.

Carborundum Co.
Perth Amboy, N. J.

H. Y. Carson
1221 Pinson St.
Birmingham 7, Ala.

Cement Gun Co.
1505 Walnut St.
Allentown, Pa.

Centriline Corp.
140 Cedar St.
New York 6, N. Y.

Chain Belt Co.
4610 W. Greenfield Ave.
Milwaukee 1, Wis.

Chapman Valve Mfg. Co.
Indian Orchard, Mass.

Chemical Equipment Co.
P. O. Box 3098, Terminal Annex
Los Angeles 54, Calif.

Chemical Fire & Rust Proofing Corp.
11-33 31st Drive
Long Island City, N. Y.

Chicago Bridge & Iron Co.
332 S. Michigan Ave.
Chicago 4, Ill.

Chicago Pump Company
622 Diversey Pkway
Chicago 14, Ill.

Cast Iron Pipe Research Assn.
112 South Michigan Ave.
Chicago 3, Ill.

H. W. Clark Company
Mattoon, Ill.

Climax Engine & Pump Mfg. Co.
208 S. LaSalle St.
Chicago 4, Ill.

James B. Clow & Son
201 N. Talman Ave.
Chicago 80, Ill.

R. D. Cole Mfg. Co.
Newnan, Ga.

Columbia-Southern Chemical Corp.
Subsidiary of Pittsburgh Plate Glass Co.
Pittsburgh 22, Pa.
(1 Gateway Center)

Combustion Engineering, Inc.
200 Madison Ave.
New York, N. Y.

Continental Can Co.
Mills Plastic Pipe Division
100 E. 42nd St.
New York 17, N. Y.

Continental Steel Corp.
Chain Link Fence Div.
Kokomo, Ind.

Cook Well Strainer Co.
3264 Beekman
Cincinnati 32, Ohio

Corey Manufacturing Co.
Dept. 23
3279 Verdugo Road
Los Angeles 65, Calif.

Crane Co.
836 S. Michigan Ave.
Chicago, Ill.

D

W. S. Darley & Co.
2810 Washington Blvd.
Chicago, Ill.

Darling Valve & Mfg. Co.
Ft. of Walnut St.
Williamsport 28, Pa.

DeLaval Steam Turbine Co.
Trenton, N. J.

The Detectron Corp.
5420 Vineland Ave.
N. Hollywood, Calif.

Diamond Alkali Co.
300 Union Commerce Bldg.
Cleveland 14, Ohio

Dorr-Oliver Corp.
Barry Place
Stamford, Conn.

Dresser Mfg. Div.
59 Fisher Ave.
Bradford, Pa.

E

Economy Pumps Inc., Div. C. H. Wheeler Mfg. Co., 19th and Lehigh
Philadelphia 32, Pa.

The Eddy Valve Company
Waterford, N. Y.

Electric Fish Screen Co.
1130 N. Poinsettia Pl.
Hollywood 46, Calif.

Electric Machinery Mfg. Co.
821 2nd Ave. S. E.
Minneapolis 13, Minn.

Electro Rust Proofing Corp.
11 Mill Road
Belleville, N. J.

Everson Mfg. Company
214 W. Huron St.
Chicago 10, Ill.

F

Fairbanks Morse & Co.
600 S. Michigan Ave.
Chicago, Ill.

Filer & Stowell Co.
147 East Becher St.
Milwaukee, Wis.

Filtration Equipment Corp.
P. O. Box 1331
Rochester, N. Y.

Filtros Inc.
East Rochester, N. Y.

Fischer & Porter Co.
51 County Line Road
Hatboro, Pa.

Flexible Pipe Cleaning Co.
9324 So. Norwalk Blvd.
Los Nietos, Calif.

Flexible Sales Corp.
3786 Durango Ave.
Los Angeles 34, Calif.

Ford Meter Box Co.
Wabash, Ind.

Foster Engineering Co.
835 Lehigh Ave.
Union, N. J.

Foxboro Corp.
85 Neponset Ave.
Foxboro, Mass.

G

General Chemical Div.
Allied Chemical & Dye Corp.
40 Rector St.
New York 6, N. Y.

General Electric Company
One River Road
Schenectady, N. Y.

General Filter Co.
923 2nd St.
Ames, Iowa

General Laboratory Supply Co.
P. O. Box 2607
Paterson, N. J.

Graver Water Conditioning Co.
216 W. 14th St.
New York 11, N. Y.

Grinnell Company, Inc.
270 W. Exchange St.
Providence, R. I.

Gruendler Crusher & Pulverizer Co.
2915-2917 No. Market
St. Louis 6, Mo.

H

Hagan Corporation
Hagan Building
Pittsburgh 30, Pa.

Hamilton Kent Mfg. Co.
427 West Grant St.
Kent, Ohio

Hammond Iron Works
630 Fifth Ave.
New York 20, N. Y.

Hardinge Co.
28 North Queen St.
York, Pa.

Healy-Ruff Company
783 Hampden Ave.
St. Paul 4, Minn.

Hersey Mfg. Co.
Cor. E. & 2nd Sts.
S. Boston, Mass.

Heresite & Chemical Co.
822 S. 14th St.
Manitowoc, Wis.

Homelite Corp.
705 Riverdale Ave.
Port Chester, N. Y.

Homestead Valve Mfg. Co.
Box 348
Coraopolis, Pa.

Hydraulic Development Co.
50 Church St.
New York, N. Y.

I

Infilco Co.
Tucson, Ariz.

Iowa Valve Co.
201 No. Talman Ave.
P. O. Box 6600-A
Chicago 80, Ill.

Irvin Subway Grating Co.
5009 27th St.
Long Island City, N. Y.

J

Jeffrey Mfg. Co.
996 No. Fourth St.
Columbus, Ohio

Johns-Manville Corp.
Box 290, 22 E. 40th St.
New York, N. Y.

Johnston Pump Co.
Pasadena 15, Calif.

John Wiley Jones Co.
Caledonia, N. Y.

K

Keasbey & Mattison Co.
Butler Ave.
Ambler, Pa.

Klett Mfg. Company
179 E. 87th St.
New York 28, N. Y.

Komline Sanderson Eng. Corp.
Peapack, N. J.

Koppers Co.
Koppers Bldg.
Pittsburgh 19, Pa.

L

Lakeside Engr. Corp.
222 West Adams St.
Chicago, Ill.

Layne & Bowler, Inc.
Box 6185
Memphis 8, Tenn.

F. B. Leopold Co., Inc.
2413 W. Carson St.
Pittsburgh, Pa.

Le Roi Co.
1706 South 68th St.
Milwaukee 14, Wis.

Leupold & Stevens
4445 N. E. Glisan
Portland 13, Oregon

Link-Belt Co.
Colmar, Pa.

Lock Joint Pipe Co.
Box 269
E. Orange, N. J.

Ludlow Valve Mfg. Co.
Ft. of Adams St.
Troy, N. Y.

Mc

McWane Cast Iron Pipe Co.
Box 2601
Birmingham, Ala.

M

M. & H. Valve Fitting Co.
Anniston, Ala.

Millipore Filter Corp.
36 Pleasant St.
Watertown 72, Mass.

Minneapolis-Honeywell Regulator Co.
Industrial Division
Wayne & Windrim Aves.
Philadelphia 44, Pa.

Morse Bros. Machinery
Denver, Colo.

J. W. Mortell Co.
580 Burch St.
Kankakee, Ill.

Mueller Co.
2501 Chestnut St.
Chattanooga, Tenn.

Murray Brothers
2438 Arthington St.
Chicago 12, Ill.

N

Natco Corp.
327 5th Ave.
Pittsburgh 22, Pa.

National Clay Pipe Mfrs. Assn.
1520 18th St. N. W.
Washington 6, D. C.

National Power Rodding Corp.
201 N. Wells St.
Chicago, Ill.

The National Supply Co.
1401 Sheridan
Springfield, Ohio

National Water Main Cleaning
50 Church St.
New York 7, N. Y.

Neptune Meter Co.
19 West 50th St.
New York 20, N. Y.

Niagara Alkali Co.
60 E. 42nd St.
New York, N. Y.

Nooter Corporation
1480 South Second St.
St. Louis 4, Mo.

Norton Co.
Worcester 6, Mass.

O

Olin Mathieson Chemical Corp.
Indus. Chem. Div.
Mathieson Bldg.
Baltimore 3, Md.

The Oliver Corp. Industrial Division
400 W. Madison
Chicago 6, Ill.

Omega Machine Co.
345 Harris Ave.
Providence, R. I.

P

Pacific Flush Tank Company
4141 Ravenswood Ave.
Chicago 13, Ill.

Payne Dean & Co.
Clinton, Conn.

Penn Salt Mfg. Co.
1000 Widner Bldg.
Philadelphia 7, Pa.

Peerless Pump Division
301 West Ave. 26th
Los Angeles 31, Calif.

Permutit Co.
330 West 42nd St.
New York, N. Y.

Philadelphia Quartz Company
Public Ledger Bldg.
Philadelphia 6, Pa.

Phipps & Bird Company
P. O. Box 2-V
Richmond 5, Va.

Pipe Linings, Inc.
2414 E. 223rd St., Box 457
Wilmington, Calif.

Pittsburgh Coke & Chemical Co.
Grant Bldg.
Pittsburgh, Pa.

Pittsburgh-Des Moines Steel Co.
3418 Neville Island
Pittsburgh, Pa.

Jos. G. Pollard Co., Inc.
New Hyde Park, N. Y.

Portland Cement Association
33 W. Grand Ave.
Chicago, Ill.

Precision Machine Company
8 Walnut St.
Somerville, Mass.

Prescott Tool Co., Inc.
Box 7 Greendale Branch
Worcester 6, Mass.

Presstite Engr. Co.
3798 Chouteau Ave.
St. Louis 10, Mo.

Price Brothers Co.
1150 East Monument Ave.
Dayton, Ohio

Proportioneers, Inc.
345 Harris Ave.
Providence 1, R. I.

R

Ranney Method Water Supplies, Inc.
841 Alton Ave.—P. O. Box 277
Columbus 19, Ohio

Reliance Chemicals Corp.
P. O. Box 6724
Houston 5, Texas

Rensselaer Valve Co.
Troy, N. Y.

Roberts Filter Mfg. Co.
607 Columbia Ave.
Darby, Pa.

Robinson Pipe Cleaner Co.
Box 300
Canonsburg, Pa.

Rockwell Mfg. Co.
400 N. Lexington Ave.
Pittsburgh, Pa.

Rodney Hunt Machine Co.
Orange, Mass.

Roots-Connersville Blower Div.
900 West Mount St.
Connersville, Ind.

Royer Foundry & Machine Co.
158 Pringle St.
Kingston, Pa.

S

Simplex Valve & Meter Co.
7 East Orange St.
Lancaster, Pa.

M. B. Skinner Co.
3502 W. Sample St.
South Bend, Ind.

A. P. Smith Mfg. Co.
545 N. Arlington Ave.
East Orange, N. J.

S. Morgan Smith Co.
500 Lincoln St.
York, Pa.

Smith & Loveless, Inc.
3427 Broadway
Meriam, Kansas

Solvent Services, Inc.
242 Latimore St.
Painesville, Ohio

Sparling Meter Co.
945 No. Main St.
Los Angeles, Calif.

Speelmon Elevated Tank Service
822 N. Court St.
Rockford, Ill.

Standard Dry Wall Products
Box X
New Eagle, Pa.

Stuart Corp.
516 N. Charles St.
Baltimore 1, Md.

T

W. A. Taylor & Co.
7300 York Road
Baltimore 4, Md.

Tennessee Corporation
619 Grant Bldg.
Atlanta 1, Ga.

U

U. S. Electrical Motors, Inc.
200 E. Slauson Ave.
Los Angeles 54, Calif.

U. S. Pipe & Foundry Co.
3300 First Ave. North
Birmingham, Ala.

U. S. Rubber Co.
1230 6th Ave.
New York, N. Y.

Universal Concrete Pipe Co.
297 South High St.
Columbus, Ohio

W

E. H. Wachs Co.
1525 N. Dayton St.
Chicago 22, Ill.

Walker Process Equipment Inc.
840 N. Russell Ave.
Aurora, Ill.

Wallace & Tiernan
11 Mill Road
Belleville 9, N. J.

Washington Aluminum Co., Inc.
Knecht Ave. and Pennsylvania Railroad
Baltimore 29, Md.

Weinman Pump Mfg. Co.
286 Spruce St.
Columbus, Ohio

Welsbach Corp.
1500 Walnut St.
Philadelphia 2, Pa.

Western Machinery Co.
760 Folsom St.
San Francisco 7, Calif.

Westinghouse Electric Corp.
Gateway Center
401 Liberty Ave.
Pittsburgh 30, Pa.

West Virginia Pulp and Paper Co.
Industrial Chemical Sales Div.
230 Park Ave.
New York, N. Y.

John Wiley & Sons, Inc.
440 Fourth Ave.
New York 16, N. Y.

Wilkinson Products Co.
3987 Chevy Chase Dr.
Pasadena 3, Calif.

A. Reed Wilson Co.
1320 McGee St.
Kansas City 6, Mo.

R. D. Wood Company
Public Ledger Bldg.
Philadelphia 5, Pa.

Woodward Iron Company
Woodward, Ala.

Worthington Corp.
401 Worthington St.
Harrison, N. J.

Worthington Gamon Meter Div.
Worthington Corp.
296 South St.
Newark 5, N. J.

Y

Yardley Plastics Co.
142 Parsons Ave.
Columbus, Ohio

Z

Zimmer & Francescan
Moline, Ill.

II. INTRODUCTORY COMMENT

Water and Sewage Works Practices

by GEORGE E. SYMONS, Ph.D.
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MODERN development of both water and sewage treatment began about 1850 and progressed rapidly only after the understanding of the germ theory of disease and the role of water as a disease carrier. Although treatment of water and sewage developed somewhat independently, the two are so related as to be one field of study.

The oneness of water and sewage treatment exists for several reasons: (1) Both deal with important phases of public health. (2) Both deal with the same liquid, subject to the same hydraulic laws. (3) Both employ certain fundamental physical and chemical processes of treatment. (4) Both are concerned with the removal of undesirable matter from the liquid. (5) Both are community problems and in the realm of public service. (6) Both, being municipal functions, are frequently subject to the same management. (7) Sewage is the used water supply of a community.

Where an individual is interested in only water, he will find it not amiss to be acquainted with sewage treatment and vice versa. This introduction to the whole field is intended to set the scene for a basic appreciation of the technical articles and discussions which appear in the Reference and Data Edition of WATER & SEWAGE WORKS, as well as other publications.

Big Business—Broad Field

Water supply is the largest tonnage business in the world and sewage treatment probably is next in size as an industry. It is not size alone but also complexity of operations in both water and sewage works which establishes a need for management and supervision. Among the problems of management, with which a superintendent, engineer, or operator must contend are financing, rate structures, office operations, public relations and policies, legal problems, and safety.

In addition to a knowledge of management, operators or supervisors of water and sewage plants need to know some fundamentals of mathematics, hydraulics, design, construction, chemistry, biology, and bacteriology. No other field of endeavor requires a working knowledge of so many different technical and scientific fields.

Functional Operations

There are certain operations which are basically functional to both water and sewage works operations. These include pumping, flow measurement, instrumentation and control, chemical handling and feeding, coagulation and sedimentation, corrosion, laboratory control and maintenance.

Pumping is a most important operation common to both water and sewage handling. The type of pump, its capacity and characteristics, suction lift, discharge pressure, power required, controls, etc. depend on the service to which a pump is to be put.

Pumps for transferring water from a surface supply to a purification plant nearby, usually operate at a low discharge pressure and are known as "low service pumps." Pumps which discharge to distribution systems at relatively high pressures are known as "high service pumps." Today, electrically driven centrifugal pumps are used almost exclusively.

Sewage generally flows by gravity to point of discharge. In some cases where this is not possible, pumps are used to elevate the sewage as high as necessary to allow for ultimate disposal by gravity flow. Pumps are used at sewage works for pumping both sewage and sludge and at lift stations on sewer systems. Sewage pumps differ from water pumps in that they usually have low discharge pressures, and construction is such as to permit passage of relatively large objects.

Flow measurement and instrumentation are essential functions in both water and sewage works operations. In water works, one of the most important factors is a knowledge and record of the amount of water pumped or treated. Flow measuring devices, through instruments, also indicate the rate in gal. per min. or total the flow over the period of operation, or give an inked record of the rate of flow. These measuring devices also can be used to control, operate, or pace other equipment such as chemical feeders.

For water works, instruments are available to indicate or record level changes in reservoirs, pressure changes in distribution systems, loss of head in filters, and other phases of operation. Controls are available for rate of flow in filters, rate of flow in distribution systems, pump operation, chemical feeder operation and filter washing and even pump operation at distant well fields or at booster stations.

In a sewage plant, flow measurement of both sewage and sludge is highly desirable. One cannot operate a sewage works properly without a knowledge of the volumes being handled and treated. For the most parts both the metering devices and the instruments are the same as those used in water plants with slight modifications.

WATER WORKS PRACTICE

The study of water supply begins with the hydrologic cycle. This is an unending natural phenomenon. Under the influence of the sun's heat, water rises, salt free, from the ocean reservoirs, is borne by the winds, and is precipitated onto the land from which it returns to the sea in various ways.

Source of Supply

Some water percolates into the earth. Most of this water passes again to the atmosphere by the process of transpiration through the foliage of vegetation. That which collects in aquifers below the surface of the ground is known as "ground water." Most of the precipitated water runs off the earth's surface and collects in streams, rivers, ponds, and lakes and is known as "surface water."

Both ground water and surface waters are used as a source of supply. Underground supplies may be shallow wells, infiltration galleries, or deep wells. Surface supplies may be rivers, impounded reservoirs, or lakes.

Distribution

The distribution system is a network of pipes with appurtenances for transporting water from the source of supply or purification plant to the customer's tap. The distribution system consists of transmission mains

of large size, arterial mains of intermediate size, and minor distributors of 4 to 12 inch size, plus valves, hydrants and service connections. Pressure may be supplied by pumps, or by pumps and distributing reservoirs, or in gravity systems by reservoir alone.

The design, capacity, and layout of a distribution system with and without storage must consider many factors: Domestic needs, fire flow needs, ground level elevations in the community, pressure requirements, future requirements and growth factors of the community. Operation of a distribution system involves: Laying of mains, maintenance of flow and pressure, loss of carrying capacity, tuberculation, corrosion, main cleaning, maintenance of valves and hydrants, pipe lining, service tapping, service and meter installation, and meter reading.

Treatment

If water as obtained from natural sources is not suitable for domestic consumption, it must receive treatment to make it acceptable. Most common treatment of surface waters is for the removal of suspended matter (turbidity) and bacteria. If the water has other undesirable characteristics such as color, tastes and odors or is hard or corrosive, treatment processes may include some special operations. Well waters are usually clear, cool, and free of tastes, odors, and bacteria and require little treatment. Occasionally well waters may be too hard for domestic and industrial use or may be corrosive or contain undesirable amounts of iron, manganese or hydrogen sulfide. These constituents can and should be removed.

The type and extent of any treatment of any water supply depends on: The use to which the water is to be put, and the kind and character of the impurities. From the standpoint of public health, the most important treatment is the removal of bacteria, but the aethestic quality of the water is almost as important to the consumer. Industrial processes may require even greater purification than domestic supplies.

Coagulation and Sedimentation

Suspended matter or turbidity removal is accomplished by chemical coagulation followed by sedimentation. Coagulation consists of the addition of small amounts of certain chemical compounds, which react in the water to form fluffy particles, called flocs. Flocs grow in size by coalescence and adsorption of turbidity and bacteria particles on the surface. When these heavy flocs settle out under fairly quiescent conditions, they tend to "sweep out" undesirable particles of turbidity and bacteria.

In coagulation it is necessary to add the coagulating chemicals in controlled amounts. For this purpose, chemical feeders are used.

Filtration

Following coagulation and sedimentation for a period of some hours, the treated water is fairly clear, but it still contains small amounts of impurities. Therefore the water is passed through sand filters, where any remaining floc, turbidity particles and bacteria are removed. When the filter tends to become clogged with these impurities, water will not pass freely through the filter, and the filters must be washed free of the "dirt" that has collected. Operation of filters at the proper rates and the washing at proper times can be controlled manually or by automatic control devices.

Tastes and Odors

Tastes and odors in water do not make it harmful for human consumption but few water consumers want water with any tastes, odor or color. Removal of these undesirables is important, particularly in surface waters. Tastes and odors may be caused by growths of algae or decay of vegetation in reservoirs, or by industrial wastes. Algae treatment may be two-pronged: Copper sulfate treatment of reservoirs to kill algae growth and prevent tastes, and treatment to remove tastes and odors in water. Treatment may be accomplished either by the addition of finely divided highly adsorbent activated carbon to remove the taste and odor producing compounds, or by adding chlorine or chlorine dioxide to react chemically and destroy the taste and odor compounds.

Color, like tastes and odors, is also undesirable in water. It is usually caused by leaching of organic vegetable matter on reservoir sites. It is removed to some extent by coagulation, and filtration, or by activated carbon and sometimes by chlorination.

Disinfection

The primary responsibility of a water utility is to supply its customers with potable water and the primary requisite of potable water is that it be free from disease producing bacteria. Although coagulation, sedimentation and filtration remove practically all bacteria, it is the process of disinfection that completes the job and insures the safety of a water supply.

Chlorination is the most common method of disinfection, although ozone, and ultraviolet light have been used in a few instances, particularly in Europe. In this country, the term "disinfection" is almost interchangeable with the term "chlorination."

There are practically no surface waters supplies that are not chlorinated and many well supplies are chlorinated as a precautionary measure. In the larger plants, chlorine is added to water as a gas dissolved in water. Chlorine gas feeders are used for this purpose to control the dosage and at the same time assure against possible leakage of the gas. In small plants, disinfection may be accomplished by feeding solutions of calcium hypochlorite. This process is usually called hypochlorination to distinguish it from chlorination with chlorine gas.

The process of chlorination has a terminology of its own relating to the point of application, method of control, and kind of residual existing after the process is complete. The method of action of chlorine, extent of kill, effect of chlorine on viruses, bacteria, and spores, the prevention of aftergrowth in mains, and the disinfection of new mains are all important phases of the process.

Fluoridation

In 1945, two experimental installations were made for the addition of 1.0 ppm of fluoride ion to community water supplies as a means of reducing tooth decay. It was the purpose of these installations to study the effect of artificially fluoridated water supplies on the incidence of dental caries in children. Previous studies on residents of communities using water containing naturally occurring fluorides in amounts of about 1 ppm had shown that persons drinking such waters had far less tooth decay than persons whose water supplies contained no fluorides.

Results at experimental installations were successful in the first few years and it was indicated that tooth decay in children drinking artificially fluoridated water decreased by 47 to 60 per cent. Endorsement of the idea of fluoridation by the Amer. Dental Assn., The Amer. Medical Assn., and the U. S. Pub. Health Service, among others, led to many other installations.

Chemicals used are sodium fluoride, sodium silico-fluoride, hydrofluosilic acid; the chemical is added to the water by carefully controlled chemical feeders. A maximum of 1.2 ppm

is added in winter and somewhat less than that in the summer months.

Softening

When water contains relatively large amounts of calcium and magnesium in combination with bicarbonate, chloride or sulfate, that water is said to be "hard." It will make curds with soap, will produce undesirable "rings around the bathtub," will consume quantities of soap without forming suds, and will deposit scale and sludge when boiled or converted to steam. All of these effects are undesirable in both home and in industry.

To overcome these objectional features, water is softened in two ways: By the addition of lime (or lime and soda ash), or by passing the water over a bed of ion-exchange material. In the lime or lime soda process, the calcium and magnesium are removed by precipitation as calcium carbonate and magnesium hydroxide, followed by sedimentation and filtration. In the ion-exchange process, the ion-exchange material has the ability to give up sodium ions in exchange for the calcium and magnesium ions thus leaving the water soft as far as soap consumption is concerned. This does not reduce the total concentration of salts in the water. If reduced chemical content is desired, several combinations of ion-exchange materials may be used with the result that water can be practically completely freed of dissolved salts. This process is known as demineralization.

Iron and Manganese

In some localities, ground water contains iron in the form of ferrous bicarbonate. Some surfaces may also contain iron compounds. When present in amounts greater than 0.2 ppm. it is undesirable and will cause rust stains in household fixtures and brown spots in laundered goods. Higher concentrations are worse. Red water is caused by iron dissolved from iron pipe lines by the corrosive action of water.

To remove iron, the water is usually aerated and passed over a coarse filtering material such as coke, where the iron is precipitated. Combinations of coagulation, aeration, and softening can also be used.

Like iron, manganese in small concentrations will cause black stains on laundered clothes and on household fixtures. Some well water contain manganese; it is also found in surface supplies taken from reservoirs, especially when the soil contains manganese and there is vegetation on the reservoir bottom to decay and produce organic and carbonic acids. Manganese may be removed from water supplies by a combination of raising the pH and aerating, or by chlorination and filtration or by coagulating with ferric salts.

Corrosion Control

One plaguing problem in water treatment is the control of corrosion in distribution systems. Even small amounts of carbon dioxide or other substances which will lower the pH below neutral, will be sufficient to cause corrosion if there is not sufficient amount of buffering alkalinity present. Electrochemical action, involving oxygen as a hydrogen acceptor is a common cause of corrosion, as is galvanic action between two points of dissimilar metal content in a pipe. Pitting and tuberculation are two undesirable results since both reduce the carrying capacity of the pipe, red water also is an undesirable result.

Treatment for corrosion control includes neutralization and pH control in the case of acidic waters or the addition of small amounts of the glassy phosphates (sodium hexametaphosphate) to prevent corrosion by the deposition of a layer of protective phosphate on the pipe surface. Carbon dioxide can be removed by aeration. The deposition of a microscopic layer of calcium carbonate on pipe, either under the influence of water softening reactions or by cathodic protection will likewise minimize corrosion.

Laboratory Control

No water works should be without some laboratory facilities. The extent of water treatment and size of the plant usually dictates the size of the laboratory, the frequency of testing, and the number and complexity of the texts to be made.

Chlorinated supplies should have equipment for determining the amount and type of chlorine residual. Surface water supplies, which employ coagulation, filtration, and disinfection will need more elaborate testing, including control tests of chlorination, and bacteriological tests on both raw and filtered water. Water softening plants will require other tests. Most surface water supplies also determine turbidity and alkalinity and tastes and odors. Reservoirs troubled with algæ sometimes require microscopic tests for control purposes.

Maintenance

Maintenance is a term applied to keeping equipment in good operating condition and repairing breakdowns. No properly run water works should be operated without a preventive maintenance program, with regular lubrication, inspection of movable mechanisms, replacement of items subject to wear, painting, main cleaning, and regular checks of valves, and service meters. Preventive maintenance can avoid costly shutdowns.

SEWAGE WORKS PRACTICE

While the distribution system of a water utility carries water under pressure to the consumer through a network of pipes and valves, the sewer system collects the same water after use, in a network of sewer lines. The dirty water in the sewers is not under pressure and flows by gravity to the final point of disposal. Sewer lines do not contain any valves, but do have manholes at intervals to admit men and equipment for cleaning. As has been pointed out previously, pumping, flow measurement and instrumentation and control are important functional operations in sewage works.

Treatment

The purpose of sewage treatment is to protect public health and to prevent nuisance conditions in the receiving body of water. All receiving bodies have a limited ability for carrying on treatment of sewage within themselves, and disposal by dilution depends entirely on that ability. When that capacity is overtaxed, it is necessary to build sewage treatment plants. The choice of processes and methods for sewage treatment will depend on the extent to which this natural capacity can be utilized and consideration must also be given to the uses of the receiving waters.

Primary treatment consists of the removal of solid particles from sewage by physical or mechanical means, i.e., screening, grit removal, grease removal, and sedimentation. Important aids to primary treatment operations include chemical precipitation, flocculation, removal of finely divided solids by aeration and vacuum flotation, and the removal of grease and fine particles by air flotation.

Secondary treatment is an oxidation or a wet burning process for the removal and stabilization of finely divided solids and colloidal matter of dissolved organic matter by means of air and the activity of living organisms.

The trickling filter and the activated sludge process are the fundamental and best known methods for

accomplishing secondary treatment. There are several important aids to secondary treatment which improve the efficiency of operation of trickling filters or activated sludge. Trickling filter operation aids include, pre-aeration, recirculation of filter effluent, roughing filters, chlorination, alternate double filtration.

Activated sludge operations and efficiency may be improved in several ways: Pre-aeration; tapered aeration or the adding of air in larger amounts at the inlet end of an aeration tank and lesser amounts along the tank as the sewage becomes oxidized; distributed input of sewage along an aeration channel while the air input is kept constant; high rate activation; and addition of chemicals, particularly an iron salt.

Contact aeration is a process whereby sewage is passed over surfaces on which biological growths develop while air is passed through the sewage. Practically all proprietary or patented treatment processes are some variation the basic processes of sedimentation and either trickling filtration or activated sludge.

Disinfection

Disinfection is the destruction of pathogenic or disease producing organisms; it is not sterilization which is the complete killing of all bacteria and other biological organisms. Disinfection is generally accomplished by the introduction of chlorine into the sewage or the introduction of a hypochlorite solution. Almost all modifications of the process of disinfection concern the point of addition of the chlorine, or the amounts of chlorine used. Chlorination also reduces B.O.D. to some extent, it controls odors, and it may be used to control sludge bulking in activated sludge and foaming in sludge digesters.

Solids Disposal

Solids disposal is not a sewage treatment process, in itself, but is a process for the treatment or handling of a by-product of sewage treatment. This by-product has a high nuisance character. In the general process of solids disposal, there are several minor problems, processes, and methods, depending on the particular solid matter being handled.

Screenings may be buried, burned, or ground and returned to the sewage flow for removal as sludge in the sedimentation tanks. Grit, which is usually a combination of sand, cinders, coffee grounds and miscellaneous items such as bottle caps, etc., may also contain large amounts of organic matter (food and garbage particles, leaves, paper, and sewage organic matter). If grit can be washed free of the organic matter or if it is relatively clean as deposited, it may be used as fill.

Grease presents a difficult problem. Its removal is messy and presents a problem in handling; it is usually burned in some crude incinerator; if it is organic in nature and discharged to sludge digestion tanks, it will digest, but if mineral in nature, it will not.

The organic matter that settles in sedimentation tanks, is called raw sludge. It is a highly noxious material, containing about 4 to 8 per cent solids which will begin to undergo decomposition in a relatively short time. Because of its high organic and bacterial content, raw sludge cannot be disposed of by spreading on ground or by burying. It can be discharged into large deep lagoons where it will undergo decomposition without nuisance conditions or it can be discharged into covered tanks where its decomposition can be controlled. In some cases sludge may be barged to sea.

Digestion, Dewatering, Incineration

When sludge is introduced into tanks in the absence of air and heated, it undergoes digestion. Gases, composed of methane and carbon dioxide are given off, the sludge assumes a black granular appearance and loses its nuisance characteristics. The concentration of solids in the sludge increases but the total amount of solid matter decreases by as much as forty per cent. When digestion is complete the sludge may be removed for ultimate disposal.

Digested sludge may be drained and dryed on sand beds, or dewatered by treatment with coagulating chemicals and filtered on vacuum filters, after which it may be dumped for fill in low areas; or it may be dried under the influence of heat after which it may be used as a fertilizer or soil conditioner. In some cases the vacuum dewatered sludge is burned in incinerators and the ashes used for fill. If the liquid sludge is washed before chemical treatment and vacuum filtration it is "elutriated."

Sludge from activated sludge treatment may be digested or filtered and dried directly for use as a soil conditioner. The humus material which sloughs off of trickling filters also may be sent to digesters or to drying and fill.

Miscellaneous Problems

As in the case of water works practice, preventive maintenance is an important part of proper operation. Sewer cleaning; cleaning sand out of settling tanks and digestion tanks; and lubrication programs are a part of maintenance. Laboratory control is very important.

Stream pollution is an important part of sewage treatment, and the studies necessary to understanding the capacity of receiving waters are complex and varied, involving such things as aquatic microbiology, oxygen depletion, reaeration, and other factors.

Industrial Waste Treatment

With more than 10,000 industries discharging wastes in the United States, it is apparent that the complexity and size of the problem is of major proportions. Industrial wastes have been classified according to source, or as inorganic, organic, etc. Generally, inorganic wastes will respond to treatment involving chemical and mechanical processes, such as sedimentation, filtration, etc. Organic wastes usually require treatment by biological processes and may or may not require chemical and mechanical processes.

There are certain basic unit processes of industrial waste treatment some or all of which may be used depending on the source of the waste. Almost all of these unit processes are the same as used in sewage treatment. For that reason, a fundamental knowledge of sewage treatment processes and results is necessary to handle the problems of industrial waste treatment.

Literature

The literature of water and sewage works practices is found in the journals of the technical associations such as the Am. Wat. Wks. Assn. and the Fed. Sew. & Ind. Was. Assns., in current technical magazines, and in reference publications such as the Reference & Data Edition of WATER & SEWAGE WORKS. There are also many books and manuals written on general and specific phases of the subject of water and sewage treatment. Lists of the most important books have been compiled by the Editors of WATER & SEWAGE WORKS magazine.

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261R	262R	263R	264R	265R	266R	267R	268R	269R	270R	271R	272R	273R
274R	275R	276R	277R	278R	279R	280R	281R	282R	283R	284R	285R	286R
287R	288R	289R	290R	291R	292R	293R	294R	295R	296R	297R	298R	299R
300R	301R	302R	303R	304R	305R	306R	307R	308R	309R	310R	311R	312R
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LINN H. ENSLOW

Editor

"Water & Sewage Works"

List No. 1—For Managers and Operators of Small Water Works

Books	*Publishers*	*Author*
American Civil Engineering Handbook—5th Ed. ($14.00)	John Wiley & Sons, New York City	Merriman & Wiggin
A.W.W.A. Recommended Practices and Specifications	Am. Water Works Assn., New York City	
Individual Reprints (Nominal Prices)		
Bul. No. 21 (a Handbook on Hydraulics) (F)	National Tube Co., Pittsburgh, Pa.	
Census of Water Treatment Plants	Am. Water Works Assn., New York, N. Y.	
Chlorine Manual (F)	The Chlorine Institute, New York, N. Y.	
Conversion Factors for Engineers (F)	Dorr-Oliver Co., Stamford, Conn.	
Copper Sulfate in Control of Microorganisms (F)	Phelps Dodge Refining Corp., New York, N. Y.	Hale
Elements of Water Supply Engineering (2nd Ed.) ($5.00)	John Wiley & Sons, New York, N. Y.	Waterman
Engineering Data in Flow of Fluids in Pipes (F)	Crane Co., Chicago, Ill.	
Fire Engine Tests and Fire Stream Tables (F)	National Board of Fire Underwriters, New York, N. Y.	
Handbook of Fire Protection ($10.00)	National Fire Protection Assn., Boston, Mass.	Crosby, Fiske & Forster
Hydraulic Tables—3rd Ed.	John Wiley & Sons, New York, N. Y.	Williams & Hazen
Lab. Manual—Water and Sewage Anal., 3rd Ed. ($4.50)	McGraw-Hill Co., New York, N. Y.	Theroux, Eldridge, Mallman
Lefax—Data Sheets for Loose Leaf Note Books	Lefax, Inc., Philadelphia, Pa.	
Manual for Water Plant Operators	Chemical Publishing Co., Brooklyn 2, N. Y.	A. A. Hirsch
Manual for Water Works Operators	Texas Water and Sewage Works Assn., c/o State Dept. Health, Austin, Tex.	
Manual of Recommended Water Sanitation Practice ($.15)	U. S. Govt. Printing Office, Washington, D. C.	
Manual of Water Quality and Treatment—2nd Ed.	Am. Water Works Assn., New York, N. Y.	
Manual of Water Works Accounting	Am. Water Works Assn., New York, N. Y.	
Microscopy of Drinking Water 4th Ed. ($12.00)	John Wiley & Sons, New York, N. Y.	Whipple-Fair
pH Control (F)	W. A. Taylor Co., Baltimore, Md.	
Plane Surveying ($6.00)	John Wiley & Sons, New York, N. Y.	Tracy
Public Water Supplies—4th Ed. ($7.00)	John Wiley & Sons, New York, N. Y.	Turneaure & Russell
Std. Meth.—Water, Sewage, Ind. Waste Exam.—10th Ed. ($7.50)	Order from APHA, AWWA or FSIWA	
Taste and Odor Control in Water Purification (F)	Industrial Chem. Sales Div., New York, N. Y.	
Technical Bulletins on Chlorination (F)	Wallace & Tiernan Co., Inc., Newark, N. J.	
The Operation of Water Filtration Plants (F)	N. C. State Dept. Health, Raleigh, N. C.	
Water Conditioning Data Books (F)	Permutit Co., New York, N. Y.	
Water Purification Control—3rd Ed.	Williams & Wilkins, Baltimore, Md.	Hopkins
Water Rate Structures in America (F)	Public Service Comm. of Wis., Madison, Wis.	
Water Supply & Treatment—3rd Ed.	National Lime Assn., Washington, D. C.	Hoover
Water Supply Control	New York State Dept. Health, Albany, N. Y.	
Water Treatment and Purification—2nd Ed. ($5.50)	McGraw-Hill Co., New York, N. Y.	Ryan
Water Works Engineering in Disaster (F)	O. C. D. Pub. No. 2022, Washington, D. C.	McCallum

(F) Available as Free Publication at this writing.

List No. 2—For Managers, Chemists and Operators of Large Water Works

(In addition to List No. 1)

Books	*Publishers*	*Author*
Applied Hydraulics—($9.50)	John Wiley & Sons, Inc., New York, N. Y.	Addison
Civil Engineering Handbook—3rd Ed. ($16.00)	McGraw-Hill Co., New York, N. Y.	Urquhart
Concrete Engineers' Handbook (New Ed. Coming)	McGraw-Hill Co., New York, N. Y.	Hool & Johnson
Corrosion: Causes and Prevention—($15.00)	John Wiley & Sons, Inc., New York, N. Y.	Uhlig
Corrosion Handbook—3rd Ed. ($11.00)	McGraw-Hill Co., New York, N. Y.	Speller
Data Book on Design for Civil Engineers—(3 Vols.)	John Wiley & Sons, Inc., New York, N. Y.	Elwyn E. Seelye
Deep Well Drilling	Gulf Publishing Co., Houston, Tex.	Walter & Jeffery
Fluoridation as a Public Health Measure—($4.50)	Am. Assn. for Adv. of Science, Washington, D. C.	
Fresh Water Biology—($10.75)	John Wiley & Sons, New York, N. Y.	Ward & Whipple
Fresh Water Algae—2nd Ed. ($11.00)	McGraw-Hill Co., New York, N. Y.	Smith
Ground Water—($9.00)	McGraw-Hill Co., New York, N. Y.	C. F. Tolman
Ground Water, Development, Uses & Conservation	Edward E. Johnson, Inc., St. Paul, Minn.	Bennison
Guiding Principles of Public Service Reg.—(3 Vols.)	Public Utilities Reports, Inc., Rochester, N. Y.	Spurr

Handbook of Applied Hydraulics—2nd Ed. ($15.00)	McGraw-Hill Co., New York, N. Y.	Davis
Handbook of Cast Iron Pipe—($5.00)	C. I. Pipe Res. Assn., Chicago, Ill.	
Hydraulics—4th Ed. ($8.00)	McGraw-Hill Co., New York, N. Y.	King
Index to Jour. of A.W.W.A.—1881 to 1933	Am. Water Wks. Assn., New York, N. Y.	
Industrial Water Supplies—(nominal charge)	Ohio Geological Survey, Columbus, Ohio	C. W. Foulk
Laboratory Control of Water Purification	Case, Sheppard, Mann Pub. Co., New York, N. Y.	Cox
Manual on Industrial Water, ASTM No. 148A	Am. Soc. for Testing Materials, Philadelphia, Pa.	
Mechanical Engineers' Handbook—12th Ed., 3 Vol.	John Wiley & Sons, New York, N. Y.	Kent
pH and Its Practical Application	Williams & Wilkins Co., Baltimore, Md.	LaMotte, Kenny & Reed
Plumbing Engineering	Pittman Publishing Co., New York, N. Y.	Cleverdon
Pocket Companion (nominal)	Carnegie-Steel Corp., New York, N. Y.	
Public Health Engineering—2 Vol.	John Wiley & Sons, Inc., New York, N. Y.	Phelps
Pump Handbook	National Press, Millbrae, Calif.	Finch
Rainfall and Runoff	MacMillan Co., New York, N. Y.	Foster
Rates and Rate Structure	Ohio State Univ., Columbus, O.	Jt. Comm. ABA, ASCE, AWWA, FISWA
Specifications and Law on Engineering Works	John Wiley & Sons, Inc., New York, N. Y.	Sadler
Standards of Hydraulic Institute—8th Ed. ($3.00)	Hydraulic Institute, New York, N. Y.	
Standard Practices for Stationary Diesel Engines—($2.50)	Diesel Engine Mfg. Assn., Chicago, Ill.	
Summary of Census Data on Water Treatment Plants in the U. S. (Reprint)	Am. Water Works Assn., New York, N. Y.	U.S.P.H.S.
Textbook of Bacteriology	D. Appleton & Co., New York, N. Y.	Zinser & Jones
The Hardy Cross Method of Distribution System Design	Univ. of Illinois Engr. Exp. Sta., Bul. No. 286	Hardy Cross
The Quest for Pure Water	Am. Water Wks. Assn., New York, N. Y.	Baker
Valve Manual ($2.00)	Mo. Water & Sew. Conf.	Lischer
Water Bacteriology—6th Ed. ($5.25)	John Wiley & Sons, New York, N. Y.	Prescott, Winslow & McCrady
Water Borne Typhoid Fever Outbreaks (nominal)	Am. Public Health Assn., New York, N. Y.	Wolman & Gorman
Water Conditioning for Industry	McGraw-Hill Co., New York, N. Y.	Powell
Water Quality & Treatment—2nd Ed.	Am. Water Works Assn., New York City	Various
Water Treatment for Industrial Uses	Reinhold Pub. Corp., New York, N. Y.	Nordell
Water Supply and Sewerage—3rd Ed. ($8.00)	McGraw-Hill Co., New York, N. Y.	Steel
Water Supply Engineering—5th Ed. ($8.50)	McGraw-Hill Co., New York, N. Y.	Babbitt & Doland
Water Supply Paper No. 658 (Quality of Waters)	U. S. Geological Survey, Washington, D. C.	Stabler

List No. 3—For Operators and Managers of Small Sewage Works

Books	*Publishers*	*Author*
Chemical Treatment of Sewage (nominal)	Am. Public Health Assn., New York, N. Y.	Committee Report
Chlorine Manual (F)	The Chlorine Institute, New York 17, N. Y.	
Federation of Sewage & Indus. Wastes Assns.	Washington, D. C.	
Manuals of Practice (Nominal):		
Lab. Manual of Water and Sewage Anal.—3rd Ed. ($4.50)	McGraw-Hill Co., New York, N. Y.	Theroux, Eldridge & Mallman
Manual for Sewage Plant Operators	Texas Water & Sewage Wks. Assn., c/o State Dept. of Health, Austin, Texas	
Operation and Control of Sewage Treatment Plants	New York State Dept. Health, Albany, N. Y.	
Principles of Sewage Treatment	National Lime Assn., Washington, D. C.	Rudolfs
Reprints of Technical Papers on Chlorine in Sewage Treatment (F)	Wallace & Tiernan Co., Inc., Newark, N. J.	
Sewage Treatment ($6.75)	John Wiley & Sons, Inc., New York, N. Y.	Imhoff and Fair
Sewerage and Sewage Disposal Textbook—2 Vol. ($8.50)	McGraw-Hill Co., New York, N. Y.	Metcalf & Eddy
Sewer Rentals—Sewage Service Charges in Cities Over 5,000 Population ($3.00). Industrial Waste Disposal Charges in Cities Over 5,000 Population ($3.00). Std. Meth.—Water, Sewage, Ind. Wastes Exam.—10th Ed. ($7.50)	Am. Public Works Assn., Chicago. Order from APHA, AWWA, or FSIWA	

List No. 4—For Managers, Chemists and Operators of Large Sewage Works

(In addition to List No. 3)

Books	*Publishers*	*Author*
Amer. Sewage Practice—3 Vol.	McGraw-Hill Co., New York, N. Y.	Metcalf & Eddy
Industrial Waste Treatment—($7.00)	McGraw-Hill Co., New York, N. Y.	Besselieyre
Modern Sewage Disposal	Federation of Sewage and Indus. Wastes Assns., Washington, D. C.	
Municipal and Rural Sanitation—4th Ed. ($8.00)	McGraw-Hill Co., Inc., New York, N. Y.	Ehlers & Steel
Rates and Rate Structures	Ohio State Univ., Columbus, O.	Jt. Comm. ABA, ASCE, AWWA, FISWA
Stream Sanitation—($5.00)	John Wiley & Sons, Inc., New York, N. Y.	Phelps
Sewage Trade Waste Treatment	Govt. Printer, Adelaide, Australia	Hodgson
Sewerage and Sewage Treatment	Intl. Text Book Co., Scranton, Pa.	Hardenberg
Water Supply and Waste Water Disposal	John Wiley & Sons, Inc., New York, N. Y.	Fair and Geyer
Sewerage and Sewage Treatment—7th Ed. ($8.00)	John Wiley & Sons, New York, N. Y.	Babbitt
Sewers (25 shillings)	Chapman & Hall, London	Bevan & Rees
The Hoover Plumbing Code (B. H. 13)—(nominal)	U. S. Bureau of Standards	

(F) Available as Free Publication at this writing.
Note—Sewage works men should examine Lists 1 and 2—also for several (F) publications of value to all alike—for instance, "Conversion Factors for Engineers" and the handbooks.

III. MANAGEMENT

NO WATER or sewage works builds and operates itself, no matter how large or small or how automatic. This means that there must be property, financing, and contact with the public. It means that there must be operating personnel, supervision and safety. In short, it means that every water or sewage works must meet the problems of management. This section is devoted to the subject of management and the problems it entails: Financing, rate structures, office operations, public relations and policies, lands, legal decisions, and safety.

Financing

Water utilities may be private, public, or industrial. Sewage works are usually municipally owned. It doesn't matter! All water and sewage utilities must be provided with finances for both capital expenditures and operations. The particular financing program utilized depends on many factors, as indicated in this outline.

I. Capital Expenditure Financing-General
   - A. Municipal Owned Water Utility
     1. General Obligation Bonds
     2. Revenue Bonds
     3. Special Tax Assessments
     4. Surplus from Operation Revenues
   - B. Privately Owned Utility
     1. Bonds
     2. Stocks
     3. Surplus from Operating Revenues
   - C. Sewage Treatment Works
     1. General Obligation Bonds
     2. Sewer Revenue Bonds
     3. Sanitary District Bonds

II. Capital Expenditures—Specific
   - A. Extensions (Water or Sewer)
     1. Special Assessments
     2. Contracts with real estate developers
     3. Surplus
   - B. Metering Programs
     1. Bonds
     2. Special Assessments
     3. Surplus

III. Operation Financing
   - A. Municipal Water Utility
     1. Charge for service
     2. Tax funds
   - B. Private Water Utility
     1. Charge for service
   - C. Sewage Works
     1. Sewage service charge
     2. Tax funds
     3. Sanitary district tax levy

Rate Schedules

There is no rate schedule problem in communities where funds for water and sewage works operations are provided out of tax levies. In other communities charges for water and/or sewage service are based, in varying degrees, on benefits received. Basically any rate for either water or sewage service must provide monies for:

1. Operating Costs: Personnel, overhead, power, supplies, maintenance, insurance.
2. Amortization of bonded indebtedness.
3. Surplus and Contingency.

From simple to complex, the various rate structures for water are: (1) Flat rate per service per unit time; (2) Rate based on number of plumbing fixtures; (3) Rate based on measured volume of water used; (4) Sliding scale rate based on water used with standby or ready to serve charge plus special charges for fire service, etc.; (5) Combination tax and sliding scale meter rate.

The simplest sewage service charge is a flat rate based on some unit of time, or of consumption, or of production in the case of industry. The simplest rate based on water consumption is some percentage of the water bill. In the case of industry more complex rates are based on quality as well as quantity of the waste; still more complicated rates are based on tax levy, water consumption and waste concentration.

Office Operations

A water or sewage works cannot operate and serve the public without an office of some sort, and every office will find it necessary to maintain records of property, operation, service and finances. The number and type of records, and degree of detail will depend on the kind of water or sewage works, its size, number of people served, type of rate structure, treatment involved and other factors.

In a water works, records are kept of distribution systems, meter installations, valves, locations, personnel, operating expenses, income, complaints and service, volume pumped, non-revenue water, treatment operations, etc. In sewage works, records are kept of sewers, manholes, overflows, volume, treatment, income, expenses, personnel.

The record forms should be designed to meet the needs of the utility. State boards of health often prescribe the general form of treatment plant records. Standard business forms may be utilized in business operations or may be specially designed to fit specific business record machines. Engineering records, meter records, etc., usually fit the personal preference of the management. In large water systems, automatic business machines and record systems aid operations as does radio dispatching of service crews.

Public Relations

In the words of the Amer. Wat. Wks. Assn., "Silent Service is Not Enough." Every water and sewage works supervisor and operation should make an effort to develop and improve good relations with the public being served. At the same time efforts should be made to keep the public conscious of the service it receives. The establishment of sound operation and service policies is an essential part of good public relations. The technical associations (AWWA and FSIWA) both foster the development of public relations programs.

Lands and Laws

All water and sewage works must own some land and must have rights of way for distribution systems or sewer lines. Some large surfaces supplies own many acres of land as reservoir sites and this land must be protected and managed. In some instances the reservoir drainage area may be farm land which can be profitably farmed in one way or another.

With the owning of property, management will have legal problems. There are laws regulating commissions, utilities and their operations, rates, etc. Legal restrictions exist regarding stream pollution, delinquent accounts, cross connections, lines in highways, etc. There are few operations in water and sewage works management that do not in some way involve legal problems.

Safety

Until the late 1940's, little serious attention was given to safety programs in water and sewage works operations. As a result, the accident incidence and severity rate in water works was higher than in other industries. More recently, the AWWA has developed a program to interest water works men. The FSIWA is also keenly interested in the problem and many articles have appeared in the technical press on the subject.

Financing Sewage Works

Some fundamental considerations

by WM. F. TEMPEST
Portland Cement Association, Chicago, Ill.

OF ALL the utility services enjoyed by any community the most essential are water and sewage works. Practically, the two services are so closely related they may be considered as one. After considering real values few will take issue with such a statement. A plentiful supply of safe water requires adequate protection and elimination of pollution. This in turn means adequate treatment works for all communities returning used water containing sewage and other impurities to water courses or ground waters. With the increase in population and the development and extension of urban communities the need for providing treatment works has become more acute. Fortunately the problem is one that is now being given more attention by all officials of local units of government.

High standards of living, bordering upon extravagance, are likely to create a false sense of values. It may be more popular in some places to advocate a community golf course rather than a sewage treatment plant, just as in a home the most needed item may be a new washing machine, but the one most desired may be a television set. Municipal officials of the community, no less than individual members of a family, are faced with the problem of maintaining a balance in providing all the services demanded including essential and the not so essential but desirable. The ever present problem for the municipality as well as the family is one of paying for the desired service or improvement.

Elementary Factors

The elementary factors affecting municipal financing of improvements are the same as those applicable to an individual. Too often individuals who make up a city council or officials who administer the affairs of a community overlook fundamentals. At the risk of oversimplification all of the problems incident to the financing of sewage works will be discussed as factors of a simple formula for borrowing money, sometimes referred to as the three "C"s, that is

$$C_1 + C_2 + C_3 = C_4.$$

Where C_1 is Capital
C_2 is Capacity
and C_3 is Character

With variable values, the sum of these equals C_4, which is *Credit* or trust in a promise for repayment of borrowed funds.

The value assigned to C_1 (Capital) will, of course, depend upon cash resources, value of properties, equipment, etc. It is a fundamental consideration but not the most important of the three factors.

The value assigned to C_2 (Capacity) is perhaps the most important when considered together with C_3 (Character), as it will generally be determinative of the final result. The earning power existing, or potential, is the measure of the capacity of a municipality to pay for improvements over a period of time. The lender will make a careful study of this factor. The value assigned to C_3 (Character) is also carefully weighed by a lender. Although merely a legal entity, the municipality or other local unit of government has character no less than a natural person when finance is considered. The integrity of a municipality, its past experience in the discharge of obligations, the type of administration and the published reports all influence an appraisal of its character.

These simple factors and a broad comprehension of what each means to the future of the community should be kept constantly before administration officials. The values are not determined overnight but only as the result of experience and a course of conduct appearing on record.

Revenue Bond Report

To illustrate a form of inquiry adopted by the Investment Bankers Association of America, both sides of two Revenue Bond Report forms for improvements are reproduced herewith. The answers to the questions on these forms together with a copy of the latest financial statement and additional comments will enable the lender or the investor to analyze the security issued in the light of the fundamental factors discussed.

These forms were prepared by the Municipal Securities Committee of the Investment Bankers Association in an effort to have necessary information collected and presented in a uniform pattern and as concise as possible. It is offered as a constructive suggestion with the hope that issuers of revenue bonds will follow it as closely as practicable in making information available to engineers. The necessity for this arises out of the development of revenue financing and the growing interest on the part of the investing public.

Application of Principles

In the past few years much has been written and considerable study undertaken on problems affecting the financing of water and sewage facilities. Of particular significance is the work of a Joint Committee sponsored by the American Society of Civil Engineers and the Section of Municipal Law of the American Bar Association. Participating organizations included:

American Water Works Association

Federation of Sewage Works Associations

Investment Bankers Association of America

Municipal Finance Officers Association

American Public Works Association

National Association of Railroad and Utilities Commissioners

The report of this joint group† has value for all those interested in the financing or administration of water and sewage works.

The report covers all phases but with particular emphasis upon the establishment of a sound basis for the rate structure and fair rates to meet the total annual revenue requirements.

The total annual revenue required is defined substantially in the following manner—

"The needed total annual revenue of a water or sewage works shall be contributed by users and non-users or properties for whose use, need and benefit the facilities of the works are provided, approximately in proportion to the cost of providing for the service and for the use of the works."

Three Types of Bonds

This fundamental concept of a rate structure designed to impose regular charges based upon service and benefits enables the municipality to operate the water and sewer facilities on a businesslike basis. It permits the finance officer to develop a well-rounded financial plan. Too often, the only available method of borrowing has been by means of general tax obligation bonds relying solely on the taxing power.

General Tax Obligation bonds are payable from a general tax on all property and consequently a direct obligation of the municipality. All bonds of this class fall within Constitutional or statutory limitations upon indebtedness. No distinction is made between revenue producing public works. Total reliance upon this method prevents flexibility and may seriously retard construction of needed improvements.

Special Assessment bonds although payable only from special assessments against property benefited nevertheless make the property owner responsible for the improvement and are considered an indebtedness of the municipality.

Revenue bonds, the third method of financing, provide for repayment from charges to be made against users, or users and properties. Such bonds are ideally suited for the financing of sewage works. Insofar as any local unit of government has some capital, good capacity for earnings, a good character and stability with honest administration, revenue bonds will be acceptable to the investor and provide an economical means of raising funds for vital needs.

Organizing An Improvement

The success of any improvement depends not only upon the soundness and the need for the project but also upon engineering judgment, well-planned financing and carefully guided legal procedure. In support of all phases there should be strong public support. No municipality should overlook this important preliminary step. It may even be profitable to engage special counsel to direct an educational campaign.

The first step by the officers of the municipality should be the organization of a committee of leading citizens who have the confidence of the entire community.

The second step will be the actual organization and conduct of the campaign. Accurate information, honestly presented, will have a salutary effect upon acceptance of the financial plan and the subsequent sale of the securities to the investor.

It is at this point that the value of "character" will be appreciated. If the municipal officials have issued interesting and informative annual reports and if good public relations have been built up with all utility users the campaign for support of new facilities or extensions will gain momentum rapidly. The following outline of a general educational campaign has been used successfully and is offered as a suggestion for others:

Educational Campaign Outline

A. Establish central committee
   1. Headquarters

†The report of the Joint Committee was published in April 1951 in the Ohio State Law Jour.

IBA FORM

Revenue Bond Report—Form No. 1

_____
(Name of issuing governmental body)

Information regarding its: (check type of facility)
( ) ELECTRIC LIGHT AND POWER REVENUE BONDS, OR
( ) SEWER REVENUE BONDS, OR
( ) TOLL BRIDGE OR HIGHWAY REVENUE BONDS, OR
( ) WATER REVENUE BONDS

Population of area served_____ (U. S. Census 19____) Date of issue_____

Amount authorized $_____ Amount issued $_____

Maturities

Amount	Rate	Date	Amount	Rate	Date	Amount	Rate	Date
$_____	____	_____	$_____	____	_____	$_____	____	_____
_____	____	_____	_____	____	_____	_____	____	_____
_____	____	_____	_____	____	_____	_____	____	_____
_____	____	_____	_____	____	_____	_____	____	_____
_____	____	_____	_____	____	_____	_____	____	_____
_____	____	_____	_____	____	_____	_____	____	_____
_____	____	_____	_____	____	_____	_____	____	_____
_____	____	_____	_____	____	_____	_____	____	_____

Call provisions, if any. If noncallable prior to maturity please so state.
_____
_____
_____

What is purpose of issue?_____
_____

If purpose is for new construction or development give engineer's estimate of gross and net revenue expected over next five years:

Gross	$_____	$_____	$_____	$_____	$_____
Net	$_____	$_____	$_____	$_____	$_____

What is peak requirement for interest and principal or sinking fund?_____

What year is peak reached?_____

Amount of outstanding revenue or other bonds which have a claim on the revenue from this project $_____

(a) Are there securities having a claim junior to this issue? Yes____ No____ If "Yes", show
Amount $_____ Maturity _____ Peak debt service requirements $_____

(b) Are there securities having a claim equal to this issue? Yes____ No____ If "Yes", show
Amount $_____ Maturity _____ Peak debt service requirements $_____

(c) Are there securities having a claim prior to this issue? Yes____ No____ If "Yes", show
Amount $_____ Maturity _____ Peak debt service requirements $_____

Schedule of rates or charges for services of the facility. Date effective_____ (Give particulars in a separate statement)

Attach condensed report of income and expenditures for the last fiscal year, compared with the same information for the same period during the preceding two years; also latest balance sheet. For the purpose see accompanying Report Form No. 2 Electric, or No. 2 Sewer, or No. 2 Toll Bridge or Highway, or No. 2 Water, depending upon the type of the facility.

(See reverse side)

Investment Bankers Association of America

Controlling covenants of the bond indenture, authorizing resolution or act. Attach separate statement, if necessary.

(a) In what order are the revenues disposed of?_____
_____
_____
_____

(b) What reserve funds are provided for and what are the requirements of each? What is the amount in each at present?

Name of reserve fund	*Requirements*	*Present Amount*
_____	_____	$_____
_____	_____	$_____
_____	_____	$_____
_____	_____	$_____
_____	_____	$_____

(c) What is the covenant or legal requirement respecting the rates to be charged for the services rendered?_____
_____
_____

(d) What are the provisions for issuance of additional bonds?_____
_____
_____
_____

(e) Is the preparation of an annual budget required? Yes____ No____
If "Yes", is a public hearing provided for? Yes____ No____

(f) Is issuer required to make public statement regularly re earnings? Yes____ No____
If "Yes", how often? _____

(g) What insurance is required?
Type _____ Amount $_____
Type _____ Amount $_____
Type _____ Amount $_____

Name of corporate trustee, if any_____

Name of consulting engineer(s), if any_____

Name of the attorney(s) approving the legality of the issue_____

Has the facility defaulted during the past 20 years for a period of 60 days or more in the payment of either principal or interest of any of its bonds or notes? Yes____ No____ If "Yes", give full particulars in a separate statement, including terms of settlement.

Is there a competitive system in operation? Yes____ No____ If "Yes" give, in a separate statement, the system's name, location and extent of its operations.

Are any contributions to be made to or received from any political body? Yes____ No____ If "Yes", give details.

Please furnish information, in a separate statement, regarding the economic background and financial condition of the issuing governmental body—location and operation; also general character of industries and transportation facilities in the area served.

Signed _____

Official Title _____

Date_____

4-29-49

W. & S. W.—REFERENCE & DATA—1955

R-21

Condensed Report of Revenue and Expenditures of the

_____

(Insert name of issuing political body)

FOR THE PERIODS SHOWN

	Fiscal Year ended ____	*Same period 1 year ago*	*Same period 2 years ago*
1. Operating Revenue	$	$	$
2. Nonoperating Revenue			
3. Total Gross Revenue	$	$	$
4. Expenditures for Operation & Maintenance (incl. payments for Employees Retirement & Disability Fund)			
5. Other charges, if any, against Gross Revenue			
6. Net Income available for debt service			
7. Interest paid on bonded debt			
8. Principal paid on bonded debt			
(a) Matured			
(b) Called			
9. Other charges against Net Income (specify various funds) *			
(a) _____			
(b) _____			
(c) _____			
(d) _____			
10. Amount available for retirement of debt by call			
11. Surplus (state to what uses surplus has been or may be put) _____			
12. Total amount of bonds issued (original & subsequent)			
13. Bonded debt at end of period (also show below)			
(a) Bank loans at end of period			
(b) Other unfunded debt at end of period			
14. Principal & Interest on bonded debt next fiscal year			
15. Maximum Principal & Interest requirement on present debt in any future fiscal year			
16. Total amount accumulated in reserve funds** (name & amount)			
_____			
_____			
_____			
_____			
17. Present book value of plant and equipment after depreciation			
18. Estimated average daily water supply (in gallons)			
19. Average daily water consumption (in gallons)			
20. Water storage capacity (in gallons)			
21. Number of customers at end of period—Residential			
Commercial			
Industrial			
All Others			
22. Gallons water consumed per customer—Residential			
Commercial			
Industrial			
All Others			

*What method of depreciation is used? _____

*What disposition is made of revenue in these funds? _____

**How are reserve funds invested? _____

(See reverse side)

R-22

Latest Balance Sheet

As of _____, _____, 19____

(Insert or attach copy)

Are there any contingent liabilities not shown in the balance sheet? Yes_____ No_____

If "Yes", explain. _____

Name and address of auditor preparing the annual audit. _____

Is the auditor an independent auditor? Yes_____ No_____

Is sewer service charge based on amount of water metered? Yes_____ No_____ If not what is the base?

Does the sewer charge appear on water bill? Yes_____ No_____

May water and sewer charges be paid separately? Yes_____ No_____ If "Yes", explain_____

If sewer charge is not paid, does it become a lien on real property? _____

May past due water bills become a lien on the property? _____

What is the source of water supply? _____

Does the system contain a sewage treatment plant? _____

Other Pertinent Data or Comments

_____

_____

_____

_____

_____

_____

_____

_____

_____

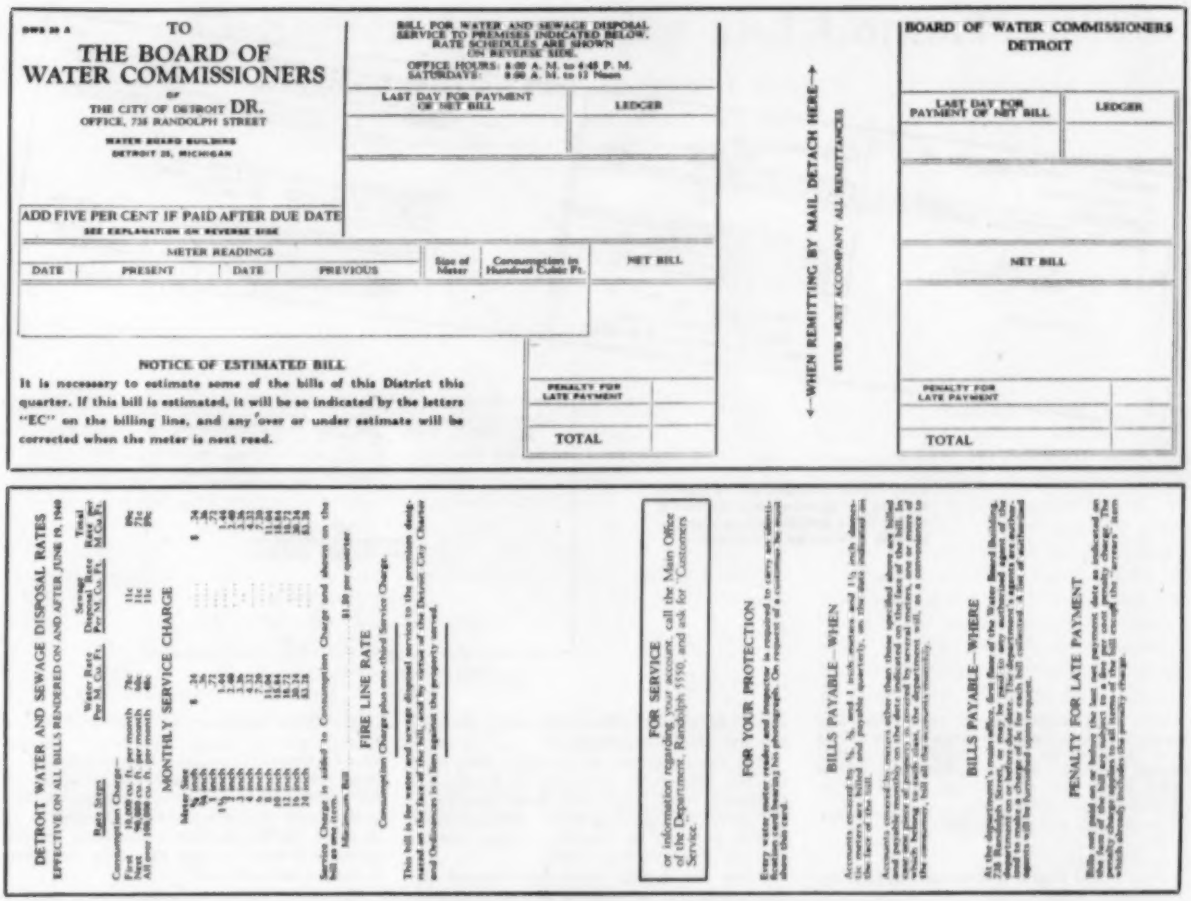
_____

Signed _____

Official Title _____

Date _____

1-10-50



TO
THE BOARD OF WATER COMMISSIONERS
OF
THE CITY OF DETROIT DR.
OFFICE, 738 RANDOLPH STREET
WATER BOARD BUILDING
DETROIT 26, MICHIGAN

BILL FOR WATER AND SEWAGE DISPOSAL SERVICE TO PREMISES INDICATED BELOW. RATE SCHEDULES ARE SHOWN ON REVERSE SIDE.
OFFICE HOURS: 8:00 A. M. to 4:45 P. M.
SATURDAY: 8:00 A. M. to 12 Noon

LAST DAY FOR PAYMENT OF NET BILL | LEDGER

ADD FIVE PER CENT IF PAID AFTER DUE DATE
SEE EXPLANATION ON REVERSE SIDE

METER READINGS: DATE | PRESENT | DATE | PREVIOUS | Size of Meter | Consumption in Hundred Cubic Ft. | NET BILL

NOTICE OF ESTIMATED BILL
It is necessary to estimate some of the bills of this District this quarter. If this bill is estimated, it will be so indicated by the letters "EC" on the billing line, and any over or under estimate will be corrected when the meter is next read.

PENALTY FOR LATE PAYMENT
TOTAL

← WHEN REMITTING BY MAIL DETACH HERE →
STUB MUST ACCOMPANY ALL REMITTANCES

BOARD OF WATER COMMISSIONERS
DETROIT

LAST DAY FOR PAYMENT OF NET BILL | LEDGER
NET BILL
PENALTY FOR LATE PAYMENT
TOTAL

DETROIT WATER AND SEWAGE DISPOSAL RATES
EFFECTIVE ON ALL BILLS RENDERED ON AND AFTER JUNE 19, 1940

MONTHLY SERVICE CHARGE

Rate Steps	Water Rate Per M Cu. Ft.	Sewage Disposal Rate Per M Cu. Ft.	Total Rate Per M Cu. Ft.
Consumption Charge—			
First 10,000 cu. ft. per month	22c	11c	33c
Next 190,000 cu. ft. per month	20c	10c	30c
All over 200,000 cu. ft. per month	18c	9c	27c

Meter Size	Service Charge
⅝"	$ 0.50
¾"	0.50
1"	0.50
1½"	0.75
2"	1.00
3"	1.50
4"	2.00
6"	3.00
8"	4.00
10"	5.00
12"	6.00

Service Charge is added to Consumption Charge and shown on the bill on the fifth Consumption Charge plus one-third Service Charge. Minimum Bill ..... $1.50 per quarter

FIRE LINE RATE

This bill is for water and sewage disposal service to the premises designated on the face of the bill, and by virtue of the Detroit City Charter and Ordinances is a lien against the property served.

FOR SERVICE
or information regarding your account, call the Main Office of the Department, Randolph 5550, and ask for "Customers Service."

FOR YOUR PROTECTION
Every water meter reader and inspector is required to carry an identification card bearing his photograph. On request of a customer he must show this card.

BILLS PAYABLE—WHEN
Accounts rendered by ⅜, ⅝, and 1 inch meters and 1½ inch domestic meters are billed and payable quarterly, on the date indicated on the face of the bill.
Accounts covered by meters other than those specified above are billed and payable monthly on the date indicated on the face of the bill. In cases where billing is made quarterly, one or more of the months' consumption will, as a convenience to the customers, be billed with the succeeding quarter.

BILLS PAYABLE—WHERE
At the department's room office, first floor of the Water Board Building, 738 Randolph Street, or may be mailed to an authorized agent of the department on or before the due date. The department's agents are authorized to collect the amount of each bill rendered. A list of authorized agents will be furnished upon request.

PENALTY FOR LATE PAYMENT
Bills not paid on or before the last day payment date as indicated on the face of the bill are subject to a penalty charge. The penalty charge applies to all items of the bill except fixed charges which already includes the penalty charge.

2. Volunteers
3. Appoint publicity director

B. Report on investigations
1. Engineer's report
2. Financing methods (advice obtained from bond attorneys)
3. Comparable conditions in other cities. How remedied?

C. Publicity
1. Newspaper articles. Full details given to press; cooperation obtained in interest of public welfare
2. Advertisements—if election to be held, present final conclusive arguments immediately preceding election day
3. Booklets and pamphlets—simple, direct statements

D. Canvassing
1. Individual calls by volunteers
2. Endorsements by prominent citizens

E. Local Organizations
1. Obtain support of local groups
   a. Business
   b. Professional
   c. Chamber of Commerce
   d. Women's Organizations
   e. Civic Clubs
   f. Schools, etc.

F. Lectures and radio talks
1. By city officials
   a. Engineers
   b. Attorneys
   c. Volunteer citizens

G. Displays
1. Posters in store windows
2. Posters in homes

The campaign should enlighten the public on the need for the project, but should not be directed exclusively to the citizens of the community. Advantage can be taken of a wider sphere of influence and facts developed during the campaign to reveal the capacity of the sewage works to earn its own way on a businesslike basis. This provides an opportunity to inform the residents of the community of the indispensable services they receive at nominal cost.

The campaign can also be used to build up the character of the municipality. The percentage of home ownership, the healthy growth of local service organizations, church attendance, the use of public libraries and community facilities are all indicative of the character of the community.

Revenue Bond Ordinance

If bond counsel has not been engaged, early employment of expert legal advice is highly recommended. Bond counsel and financial consultants should work in close harmony through all steps in the procedure.

In the event of any challenge on a point of procedure or the possible contest on the validity of an ordinance bond counsel is better able to defend the action if thoroughly familiar with all on-the-spot discussions. Particular attention should be given to the drafting of the bond ordinance. Some typical provisions of a Revenue bond ordinance are given below, but for a more detailed discussion the reader would do well to refer to a paper entitled "Financing Through Revenue Bonds" published by the National Institute of Municipal Law Officers as Report No. 107.

Typical provisions of a revenue bond ordinance are illustrated in the following outline:

ORDINANCE NO. .....

Title:
An Ordinance Authorizing the Construction and Operation of a Sewage Treatment and Disposal System for the City of.....: pursuant to the act of the.....legislature known as the.....act of..... and further under the act of the..... legislature known as the.....act to provide for the financing of construction operation, improvements, extensions and betterments by the issuance of Sewer Revenue Bonds, payable solely from sewer service charges and revenue derived from the operation of the system and to provide funds for paying all or a part of the cost of such system; providing that such Sewer Revenue Bonds shall not constitute a debt of the City or a pledge of its full faith and credit; requiring connections with sanitary sewers to be served by such system; providing for the imposition and collection of rates, fees and charges for use of services and facilities of the system and for the creation of certain special funds; pledging the net revenues of the system to the payment of principal and interest obligations on such Sewer Revenue Bonds and setting forth the rights and remedies of the holders of such bonds.

Resolution:
(Set forth in detail necessity for project, its extent, purpose, authority to act, also descriptive details of project with enumeration of all facilities.)

Ordinance Proper:
Article I—(Detailed definitions)
Article II—(Set out in detail authority for issue, form and provision for registration of bonds. Accurate description and designation of bonds should be given together with interest provisions and denomination of bonds. There should be a section devoted to transfer provisions stating specifically how title to any bond shall pass. It is especially important to

Combination postcard billing form to provide office record and follow-up notice. In the machine billing operation the strip is cut on the dashed lines.

provide for negotiability in appropriate language declaring the bonds negotiable with the same incidents as other similar instruments payable to bearer. Place of payment should be stated which for convenience should be an established financial center.)

Other sections will provide for:

1. Reserve Fund.
2. Amortization.
3. Notice and Right of Redemption and Redemption Price.
4. Issuance of duplicate in case of loss.
5. Covenants.
6. Remedies.

Consultants Are Important

The financial consultant will study special phases of the finance problems such as timing of the issue, coupon rates, manner of issue and many other similar details on which one familiar with municipal finance will have special knowledge.

Many of the steps necessary to be taken in planning for the financing of sewage works will necessarily be taken at the same time. The selection of the consulting engineer, for example, is an important matter to be decided as early as possible. His knowledge of the project requirements and his study of rate structures, more important now than ever before, will enable him to contribute valuable information desired by both legal counsel and financial consultant. Municipal officials should not overlook the tremendous advantage of conferences throughout the proceedings from beginning to end which include bond counsel, financial consultant and engineer. In this manner common problems can be resolved to the ultimate benefit of the municipality.

When it becomes necessary to decide upon the type of bonds and the manner in which they should be issued and sold, reliance should be placed in the advice of bond counsel and financial consultant.

The bond attorney in company with local officials should be prepared to discuss the proposed bond issue with bond dealers in the large financial centers. Ordinarily it is not possible to finance a large project entirely through local dealers.

After all details have been ironed out the bonds will be ordered issued in accordance with the plan decided upon and in the order and amount specified. At this point also the educational campaign will be of material help in smoothing the path of the steps that follow. A prospectus will have been prepared, giving a clear outline of local finances, prior obligations, assessed valuation, number of users and estimated income. If the job is well done and confidence has been created in the reports of the engineer and others connected with various phases of the proposed improvement, the prospectus will be well received by investors. It should be at once apparent from all that has been said that every step must be given careful thought and decisions made only after thorough study and deliberation. This groundwork all along the way is of extreme importance to the municipality and cannot be overemphasized.

Billing and Collection

Following the successful financing and construction of the improvement will come the problems of billing and collecting accounts. Considerable work has been done and reports of a Committee of the American Water Works Assn. studying this subject have been published in the Journal of that Association.

The most convenient basis is a joint billing of water and sewer accounts where possible. This presupposes a metered water supply and a charge for sewer service based primarily on water consumption. The most common practice is to show the charge for water and sewer service charge as separate items on the same bill. Prompt payment of the bill is often encouraged by discount privileges which can only be taken if both items are paid.

It is essential for the maintenance of good credit that a good follow-up system be adopted to prevent delinquencies. Usually a post card reminder is all that is necessary. If it becomes necessary to apply legal sanctions to enforce payment there is authority for the water shut-off device. In a survey of numerous municipalities made by the Joint Committee of the Section of Municipal Law of the American Bar Assn. and the American Society of Civil Engineers, previously referred to, it appears that the threat of water shut-off is the most effective means of enforcing payment. As a practical matter it is seldom necessary to invoke this sanction.

The methods of enforcing payment of water and sewage charges are discussed in detail in the report of the Joint Committee previously mentioned. The growing acceptance of the revenue bond method of financing sewage works will encourage municipal officials to develop information based upon experience. The exchange of knowledge guided by reports of intensive study by those vitally interested will result in healthy growth and businesslike management of the two most essential public services affecting the health and welfare of large and small communities throughout the United States.

Customer Accounting and Contact*

by R. W. FITZGERALD and ERNEST C. NORTH

Respectively Supt., Div. of Water Supply, Norfolk, Va., and
Engr. in Charge, Valuation Dept., Whitman, Requardt & Assocs., Baltimore, Md.

THE Div. of Water Supply of the Norfolk, Va., Dept of Public Works serves a metropolitan population of approximately 350,000. The customer contact and accounting procedures employed in the past were quite inefficient. Like many other cities of comparable size, Norfolk had a long established system of accounting, which, though adequate when installed, had been modified by patchwork changes in order to keep pace with rapid customer expansion. As a result of the extreme wartime growth in the number of customers, the "patches" cracked at the seams and the continued use of the old system could no longer be tolerated. In February 1948 the firm of Whitman, Requardt and Associates, Cons. Engrs., Baltimore, Md., presented a comprehensive report on the Norfolk water system, including an appraisal of customer accounting.

*Reprinted from the Jour. Amer. Wat. Wks. Assn.; Vol. 46, No. 2 (Feb. 1954) by permission of AWWA.

Redistricting

The first step to be taken was the redistricting of accounts in order to equalize the daily flow of work through the meter reading, billing, collecting, and accounting sections. Under the old system, the city had been divided into six billing districts, which had expanded at different rates. In 1947 the largest district had 10,000 customers and the smallest 3,800. The result was that the billings for over-expanded districts fell far behind the others, and collections and credit information were likewise in arrears. In view of the disparity in district size, it was obviously uneconomical to base the number of personnel on the needs of larger districts. Thus, the redistricting of the customer accounts into a more flexible pattern became of paramount importance. As sufficient office workers were not available within the division to accomplish this

Fig. 1. OFFICE of Division of Water
An attractive office invites customers' contacts.

Fig. 2. FILE room
The record cards in Fig. 2-4 are housed in file banks such as those shown at right of photograph.

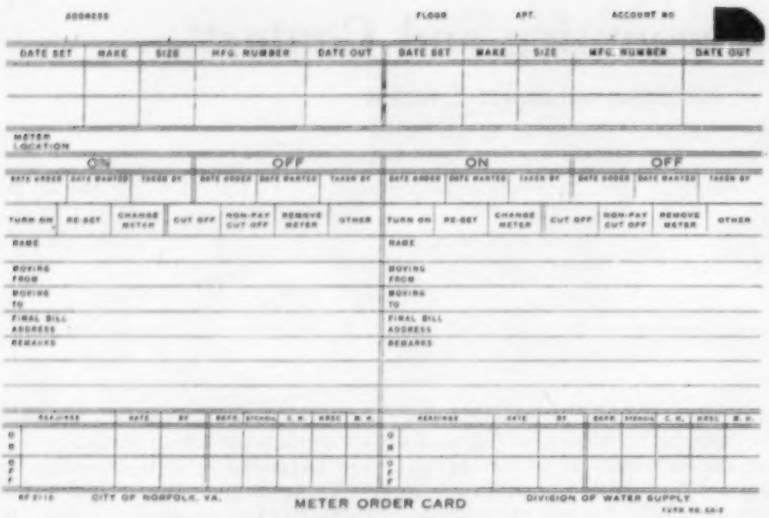


Fig. 3. METER order card
Both front and back of this card are utilized.

task, specifications were prepared and public bids requested. Remington Rand, Inc., New York, was the successful bidder. The work included address verification, meter book checks, new district and route arrangement, refolioing, verifying address plate changes, preparing new meter book indexes, and compiling a street directory. This portion of the modernization program was completed in 6 months and immediately proved beneficial to the division. Much remained to be done, however, in order to modernize the system completely.

Improved Customer Contact

Private utilities had long been conscious of the value of good customer relations and had educated the public to expect and demand like service from municipally owned utilities. Once the redistricting of accounts had smoothed out the work load on the division personnel, the next important step was the development of an "open-door" service and information section. Under the old system, the customer was required to make his contact through an old-style teller's window. Obviously, this was never the warmest or most practical type of contact, regardless of the amiability and courtesy of the clerks. The public resents the "locked-out" feeling of standing behind an opaque glass partition while the clerk scurries around the office in an attempt to gather such information as he needs to satisfy the customer.

The division has now taken a page from the private utilities' book, and the public is now served by trained personnel in comfortable and pleasant surroundings. When a customer submits a problem or question on service or billing, an intercommunication system enables the contact clerk to secure promptly all of the information required. The development of the "open-door" policy, however, made it necessary to install a modern bookkeeping system and a central filing system for customer service and history records.

Records and Accounting

The old method of bookkeeping was based on the so-called Boston ledger. These ledgers were kept in the office, convenient to contact and posting clerks. It was, of course, necessary for the billing section, located on another floor of the building to use the ledgers also. Consequently, a great deal of confusion and loss of time was inevitable. If a contact or posting clerk needed to refer to a ledger that was being used in the billing section, he had to go out of the main office into the public area, walk down a long flight of stairs to the billing section, and interrupt a biller for the length of time required to search the ledger. The customer meanwhile had to stand outside the window and wait for the "traveler" to return with the information.

The system had other faults as well. After a district had been billed,

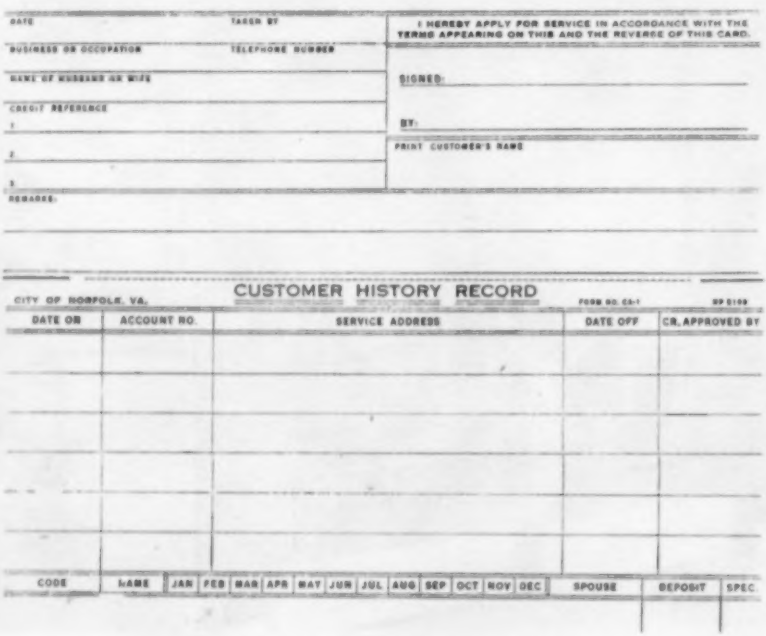


Fig. 4. CUSTOMER history record
Both the front and back of this card may be utilized to record all pertinent details of the customer's history.

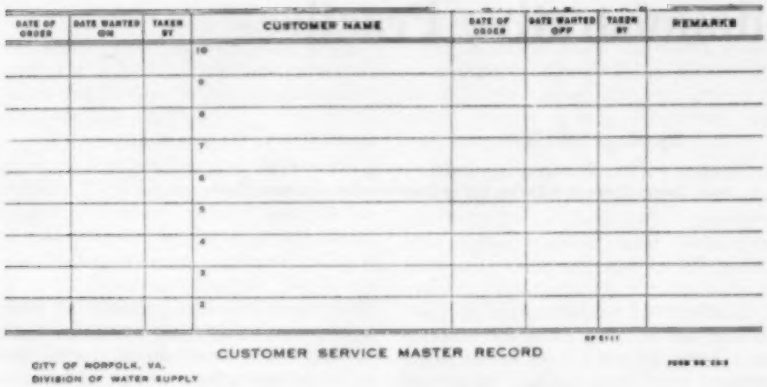


Fig. 5. CUSTOMER service master record
This card is retained in the file at all times.

the stubs from the billing section were filed by account number at a duplicate-bill window. When a duplicate was required and the account number was not known, it was necessary to refer to an address file to get the number. A cashier's stub was then prepared by hand and the customer was sent to the cashier's window for payment. The cashier sent the receipted bill stubs to the accounting section with an adding machine tape attached. A posting clerk looked up the account in the ledger, stamped the account "paid," and at the same time enumerated the paid totals on another adding machine tape. The cashier's tape and the posting clerk's tape were then reconciled. The accountant entered receipts from the posting clerk and offset these daily by cashier deposits.

Such a crude method naturally led to many errors. It had been the custom of the department to send a delinquent notice on all bills not paid in 30 days. When the time arrived for mailing the notices, it was necessary to search the ledgers for unpaid accounts. Once again "the battle of the ledgers" had to be reenacted. Contact clerks, posting clerks, and the billing section were constantly colliding.

With the development of the "open-door" policy, the ledgers were replaced by two unit booking desks housing a modern system of stub accounting. A central information file was established, using visible-index cards (Fig. 2-6). Two sets of records are maintained, one for customer history and the other for customer service. When the information and service clerk calls the file room, he is immediately routed to the proper section, where the desired data are quickly found. The division services 50,000 active accounts, and it is obvious that considerable time is saved through this efficient system.

Billing Machines

The billing system previously used had many defects, including the inability to provide useful statistics as a byproduct of the billing operation. The efficient management of a water system like Norfolk's requires such data as the water consumption by districts, the number of customers in each district, and the amount of arrears being billed by district. These statistics must be currently available, so that management can act promptly to correct any defects that may arise.

The billing machines now installed are sufficiently flexible to give the needed statistics as a simultaneous byproduct of the normal billing operation, with greater speed and accuracy than was possible with the machines and methods formerly used. The present practice is to use a postcard bill. Considerable time and money are saved, because bills are now printed by the division on a modern bill printing and addressing machine. The bills are preprinted and addressed on a cycle preparation basis.

The completely modernized system of meter reading, billing, collecting, accounting, and customer contact has now been in service for more than 2 years. Customer complaints are diminishing in number, and the irritated customer is becoming a rarity. The morale of the division's personnel is high, while the taxpayers are reaping benefits in the saving of time and money because of the improvements adopted.

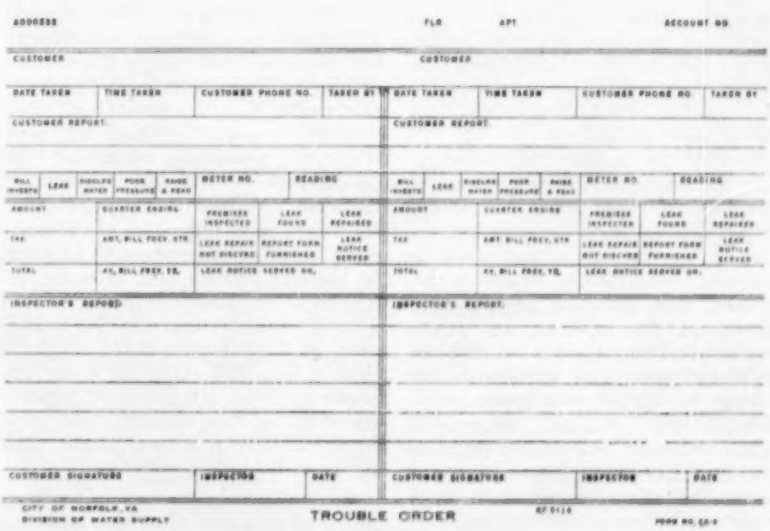


Fig. 6. TROUBLE order card
This card is taken along whenever an investigation of a service is made. Afterward the card is returned to the service file.

Better Administrative Practices*

by M. J. SHELTON

Gen. Mgr. and Chief Engr., La Mesa, Lemon Grove and Spring Valley Irrigation Dist., La Mesa, Calif.

THE water works manager normally looks to the customer and taxpayer for additional income to meet the continually increasing expenses of operation. The reduced purchasing power of the dollar and the growth in water demand since the end of World War II have combined to make this basic problem more pressing than ever. Many utilities have tried to get along on their old rates, reducing their expenses by eliminating certain services formerly rendered and by postponing maintenance and replacement. This apparent economy actually becomes a greater burden as time goes on. Still, the necessity of raising rates is a difficult one to face, and, in the presence of adverse public reaction, the governing body usually postpones the increase. The La Mesa, Lemon Grove, and Spring Valley Irrigation Dist. has been confronted with such a problem, and the purpose of this paper is to describe how improved administative practices have enabled the district to give service without raising rates, despite a tremendous rise in demand.

The district, which is located to the east of and adjecent to San Diego, Calif., contains 22,651 acres, including a population of 67,000 in 1952—more than 5½ times the 1940 figure. As a result of this urbanization, the district has been forced to convert its operations from irrigation to domestic water supply.

In 1945 the district had one engineer, its manager. Problems brought about by the rapid growth made necessary the addition of qualified engineers, so that operations could be analyzed, additional records developed, and facilities properly designed, on the basis of adequate board of directors has established additional rules and regulations resulting in higher standards, equitable division of costs, improved public relations, and greater personal efficiency. In 1951 the board employed an administative consultant to make a study of office procedures and recommend improvements. The report was submitted in June of that year. Nearly all of the recommendations have been adopted, and many other changes have been made. The cost of the survey was small, particularly when compared with the tremendous benefits that have been realized.

Shortly after completion of the administrative survey, the position of business manager was created. He works closely with the general manager, being responsible for administrative details such as personnel, accounting, billing, purchasing, warehousing, office procedures, and customer relations.

It was determined at the outset that a given procedure or operation would not be accepted as necessary merely because it was long established. Starting with the most flagrant deficiencies, changes were brought about within the office and in the field, and even basic policies of the board of directors were reviewed. In consequence, duplication of records has been eliminated; greater labor efficiency has been achieved through motion studies and increased machine operation, with a resulting reduction in both field and office personnel; extension policies have been improved; a clear-cut budget control procedure has been adopted; an entirely new system of map records has been instituted; suggestions from employees have been encouraged by awards for those accepted; and, most recently, a pension system has been instituted, providing additional employee benefits that will still further decrease an already very low labor turnover. Some indication of the monetary value of these changes is given by the fact that the cost of water delivered to the consumer dropped from 17.2 cents per 100 cu ft in 1948 to 14.0 cents in 1952. During this period the district was also replacing many obsolete pipelines and generally improving water quality, quantity, and pressure—actually at a pace greater than the growth of the population.

Technological advances are facilitating, and changes in public attitudes and demands are constantly requiring, higher standards and better service. In such circumstances, obsolescence is normal, but it may arrive more rapidly than expected. The problem of management is to establish methods of detecting it, to maintain alertness, and to revise operations and procedures as appropriate.

Organization and Personnel

As previously indicated, the district is governed by a board of directors, consisting of five men whose terms are staggered. Elections are held every 2 years and the members serve for 4 years. The board operates in the same manner as a city council, under a section of the California water code governing irrigation districts. An assessor-collector-treasurer is also elected, and the board appoints an attorney, secretary, general manager-chief engineer, and business manager. The rest of the employees in the organization are hired by the latter. All operations are carried out on a 40-hr week basis, including those of emergency crews. Overtime is held to an absolute minimum.

Engineering has played a most important part in the district's activities in the past few years because of population growth in the area. That department has, therefore, been enlarged, whereas all others are actually smaller than they were a few years ago. Although the number of accounts has more than doubled since January 1948, the district has added only one employee to the main office staff and one to the outside force.

One of the first steps taken was to review the existing salary schedule to see that it was reasonably in line with that prevailing in other public bodies in the area, making due allowance for such differences as the absence of a pension system for district employees. After 1951, when district employees were first covered by the Federal Social Security System, it became feasible to establish a retirement system, which had previously been precluded by the large number of employees with long service. Such a plan was initiated in 1953, with 95 per cent participation on the part of those eligible.

The district now follows a general policy of employing younger people and tries to obtain college men for the

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more important positions. Experience has shown that the additional amount paid for a better qualified person is more than offset by his greater effectiveness and adaptability.

An innovation started in 1951 was an employee grading and interviewing system. Each foreman grades his men in every 6-month period, and his report is reviewed by the superintendent, who makes notations before turning it in to the business manager. The latter then personally reviews the grading sheet with the employee in a private conference; in addition, he asks for any criticisms or suggestions that the employee might have. These interviews have been most beneficial in improving personnel relations and developing better operations. Upon completion of the reviews by the business manager, he meets with the superintendent and general manager to go over each man's record and determine whether he is to be recommended for an increase in salary. The recommendations are then presented to the board of directors for formal action.

Office Rearrangement

An early change was the complete rearrangement of the office. In the past, there had been an aisle down the middle of the office, dividing it into two parts. On one side was the "water department" and, on the other, the "tax department," each with its own counter and collectors. The result was that the public would often call at the wrong department and have to be referred to the right one, making for lost motion on the part of an employee, as well as inconvenience to the customer. Even more important was the fact that the employees of one department were never used to relieve the work load in the other.

Under the new arrangement, the two departments were combined into one. Small separate offices were eliminated and the business manager was located at the rear center, where he could oversee all activities. The counters have been attractively redesigned, and the telephone switchboard is now situated near the main entrance, so that the operator can also serve as information clerk. Full use is made of the time of all employees, work assignments being given out by the chief clerk. In accordance with the findings of motion studies, desks have been so placed that a person takes as few steps as possible to perform his job. Maps are easily accessible to both the public and the employees. A drinking fountain formerly installed at the rear of the office for personnel use has been moved to the front, so that visitors can drink the water which is delivered by the district —a worth-while public relations device. A single clerk has been placed in charge of a central file, thus minimizing the possibility of misfiling while greatly cutting down the time consumed in locating documents.

Each person in the office is assigned a primary function but works at other positions for a sufficient time to become thoroughly familiar with them. This policy of understudies for all operations has been applied in every section, both in the office and in the field. A written job description, describing all functions or duties, has been drawn up for every position, thereby further insuring continuity of action in the event of absence of an employee.

Forms

The administrative survey had indicated considerable duplication and lack of coordination in the preparation and use of forms. The business manager obtained a copy of every form in use and began a study to see whether it was necessary, what was done with the information, who received it, and whether it was temporary or permanent. Interviews were held with the persons who regularly initiated or received the farm to determine if it could be eliminated, combined with others, or simplified. The number of forms in use was reduced materially, saving labor, time, and filing space.

Standard Procedures

As the administrative modernization got under way, it became apparent that there should be a permanent system of advising all affected persons and at the same time making available for the future a ready reference source on policies and procedures. This was accomplished by the issuance of executive orders, standard practices, board memoranda, and the like. Department heads receive copies as issued and place them in a loose-leaf book, where they are easily accessible.

Machine Operations

Before the administrative survey was made, the single billing machine on hand had to be operated overtime to keep up with the billing schedule. A review of billing practices simplified the work, eliminated some steps, and made possible the preparation of all bills well within regular work hours. The meter reader's sheets were revised to assist both him and the billing-machine operator. The bulky, large-size individual water account cards formerly kept on permanent file have been eliminated. Billing data are now printed on a small card simultaneously with the customer's bill. The cards are destroyed after a year, as a permanent record is still available in the meter book. Calculating machines, typewriters, and other such equipment are replaced on a regular schedule in order to obtain maximum efficiency.

A wire recorder, acquired to save stenographers time in taking dictation, has also proved valuable for recording telephone calls and conference discussions. A photostat machine is used to make copies of maps, letters, and other documents, and a blueprinting machine in the engineering department can likewise be employed for this purpose.

Improvements in machine operations were not limited to the office, but were made in the field as well. In this connection, the board of directors' policy of awards for suggestions has proved fruitful. A wagon drill has been adapted for drilling services under roads, with very great savings in time, labor, pavement repair, and inconvenience to the public. A small service trenching machine was developed, and study is being given to a drill that will permit the placement of a new copper service inside an old galvanized-iron pipe.

Collections

It has always been recognized that peaks in office routine should be eliminated. To this end, the district has for years contracted with banks and drugstores to serve as collection stations. This policy has been extended to include express offices, which will receive payment at any of their branches, regardless of location. All bills carry a listing of the collection stations, as well as a note recommending payment by check. This campaign has increased collections through these media, so that the growth in the utility's business has not necessitated adding more tellers at the office. In fact, the number has actually been reduced by one, as a result of the office rearrangement.

Calendar Check List

The job descriptions mentioned earlier indicate when a certain report is due, when contact is to be made, and the like. As a further safeguard against oversights, the business manager maintains a calendar of such items. Related matters, such as fire and property damage insurance, are now attended to on the same date, if practicable. The business manager, through the chief clerk, reminds the persons concerned well in advance of due dates.

Budget

Although, in the past, an annual projection of expected revenues and expenditures was made by the district, no true budget was prepared. It is now the responsibility of the business manager to coordinate the efforts of all departments in the preparation of such a budget and to maintain control throughout the year. Every department makes a careful study and tabulation of the anticipated work, giving costs and justifications. This information is brought together by the business manager, who, after thorough analysis, reviews it with the general manager. The entire budget study is then presented to the board of directors and examined in detail with them at meetings held during June. After final adoption by the board of directors, the budget is used as a guide in authorizing construction projects or purchases involving capital outlay as they come up. Two years of experience with this procedure indicates that all department heads cooperate fully, that there is improved coordination in the planning of projects, and that less work is performed and charged to so-called maintenance accounts, resulting in very substantial savings.

The district system still has many miles of substandard pipe in service, acquired from existing utilities when the district was formed. This condition, together with the very rapid development of the area, often necessitates unanticipated expenditures. Consequently, the budget includes a considerable fund to meet such situations.

Communications

For a number of years, the district has maintained six radiotelephone-equipped cars, this utility having been one of the first to take advantage of the service when it was introduced by the telephone company. With expanding operations made necessary by the growth of the area served, it was determined to increase the number of radio-equipped cars to a total of twelve. A thorough study showed that twelve three-way radio units would approximate the cost of six additional radiotelephone units installed by the telephone company (based on a 10-year life, with full allowance for maintenance, depreciation, and other expenses). The principal argument for conversion to the three-way radio was the fact that the radiotelephone channels had become overloaded, often causing long delays. Although a radio unit is not in contact with all land phones, this disadvantage is offset by the ability to hear the conversations of all other units and thus keep abreast of the situation. Furthermore, the radio cars can communicate not only with each other but also with the telephone operator at the base station, who normally handles customer calls.

Emergency calls from customers during off-duty hours present a problem. In the past, the district listing in the telephone book included the home numbers of all emergency personnel, as well as the superintendent. The result was that a customer often had to make several calls to reach an employee on standby duty. Retaining an employee at the office or shop at all hours would have been far too expensive, and it seemed impractical to have the police receive the calls. The solution adopted was to arrange for all off-hour calls to be taken by an answering service, at a cost of only $25 per month. The district informs the answering service of the names, responsibilities, and telephone numbers of men on standby duty, so that the telephone operator can get in touch with the right person, depending on the nature of the complaint. In this way, off-duty men get their rest and the customer has to make only one call, which is handled by a trained operator. This service has been in effect since the beginning of 1953 and has proved to be very satisfactory.

Leasing of Automotive Equipment

Detailed analysis indicated that the district might be able to lease automotive equipment at a saving over the former plan of operating its own fleet and shops. After considerable negotiation with a number of possible bidders, the district contracted with one of the local dealers for 29 vehicles, ranging from sedans to flat-bed and dump trucks. The sedans and pickups are furnished on a 2-year replacement basis, the larger trucks on a 3-year basis. The dealer makes all mechanical repairs, supplies oil, batteries, and tires, and services the vehicles in the district's yard at the close of the day. The district furnishes gasoline and insurance only.

The benefits from this program are numerous: the district always has a modern fleet, which makes a good impression on the public; delays due to repairs are at a minimum; labor time equal to that of 4½ men is available for other purposes; the shop need be used only for preventive maintenance on heavy construction equipment; administration by the management and superintendent has been eliminated; purchase orders have been reduced one-third; and inventories of repair parts and tires are unnecessary, thereby releasing funds for other projects. All this has been accomplished with the same cash outlay as was required by former operations, but funds previously tied up in capital have been released for water main installations. A further advantage of the new procedure is that the costs are known in advance for the entire year, payments being made monthly at a fixed rate per unit. It is planned to place all automotive equipment, except that for heavy construction, on a lease basis within the next year.

Distribution System Records

Conversion from irrigation to domestic service has brought about many changes in the district's distribution system, which, in turn, have necessitated the development of a master plan that is annually reviewed and amended to meet new conditions. System records are the full-time responsibility of one engineer, who checks all facilities installed and keeps up with current construction. Drawings and descriptions are prepared to predetermined standards and are filed and indexed for ready reference. The photostat machine is used to reduce record drawings to the property scale, and additional data are drawn on the prints. This procedure eliminates 75-80 per cent of the drafting work and expense.

To replace the cumbersome and sometimes inaccurate maps that have been maintained since the inception of the district in 1926, a map-making project was started in July 1952. All base sheets are now completed and in use in the tax department. New wall maps are also in use, and pipeline data are being recorded on a second set of tracings. Meters are located relative to property lines; the size and type of service, the account number, and the address are shown; pipeline data include the date of installation, size and type of pipe, work order number, and location relative to centerline. Elevations are shown wherever such data are available, and eventually it is planned to include contours. Full use of the photostat machine has been made in reducing layout time by bringing record maps into the proper scale, so that they can be traced.

An attempt was made to contract the entire project, but none of the regular map-making companies was interested and one local engineering company's bid was so much higher than the estimated cost that the board of directors authorized performance of the work by district forces. The project is set up as a special department, removed from other activities, so that the work can be carried on without interruption. To date, prog-

ress and costs have been well within the estimates.

Extension Policies

The board of directors has established basic policies pertaining to granting of service to customers who do not front on pipelines, as well as regarding the installation of facilities in new developments. In the former, the district requires the owner to sign an agreement stating that, when and if a pipeline is installed, he will pay front-foot costs based on 6-in. pipe. The document is recorded, and each prospective owner of property so covered is informed of his responsibility whenever a title search is made. Upon the signing of such an agreement, temporary service is given from the nearest main.

Whenever an individual or developer inquires about new pipelines, the engineering department prepares a cost estimate and makes a schematic layout indicating the size, location, and type of pipe, and the location of valves and fire hydrants. This information is shown on a printed form, which is furnished to the person inquiring, with copies being placed on file. The owner must employ a private engineer and contractor, as the district does not do any construction itself, with minor exceptions. Payment of the estimated cost must, however, be made to the district before work can start, and the owner has to send the district a form letter stating the name of the contractor, the amount of the contract for installation, the expected date of starting and completion of the job, and the name of the party to whom the district is to make payment. Thus, the contractor is assured of payment, and the work is performed according to plans approved by the district. Any funds not needed are returned to the owner upon completion and acceptance. The district makes spot checks to determine that the facilities are installed as planned. The district disinfects the new lines and makes the connection to the system. All other work is done by the contractor, including excavation for the district main connection. By following this policy of having the owner finance the extension himself, the district can conserve its funds for necessary projects.

The results of the administrative changes described have been gratifying, but a constant search for means of further improvement is being maintained. It is hoped that other utilities will find application for some of the measures that have benefited the La Mesa Dist.

R&D

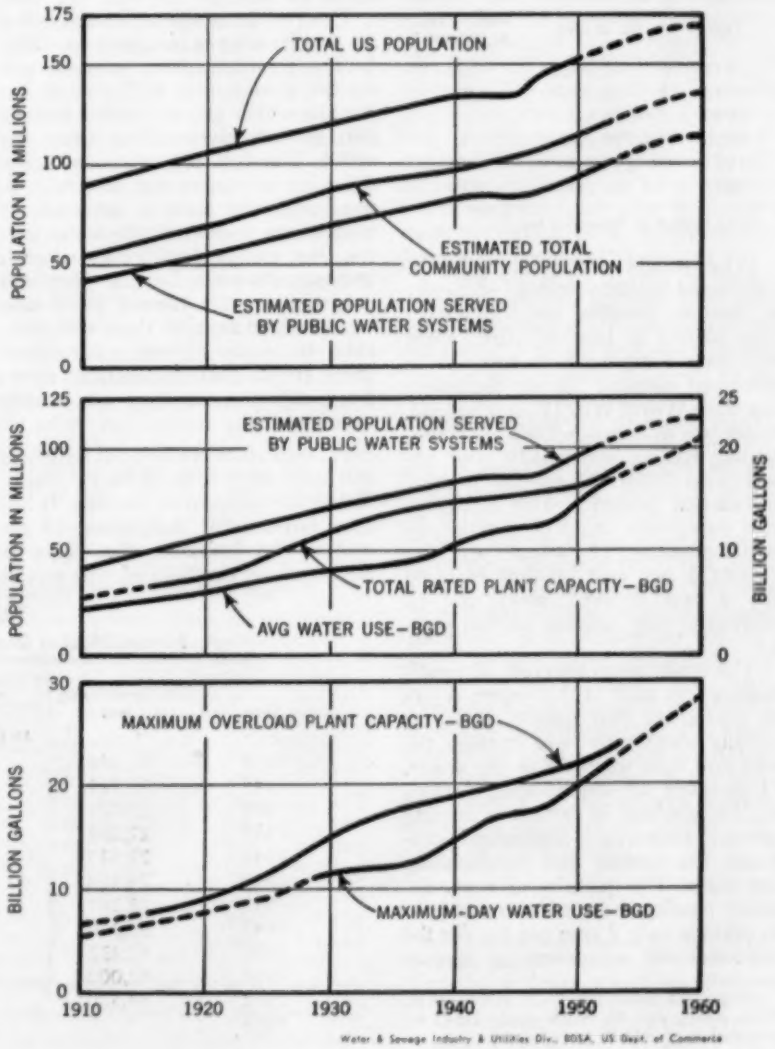
What's Happening In Water Works

The wide-awake water works manager must consider the future demand on his water supply system. This too, is part of "Better Administrative Practices." It is not enough for a manager to develop an organization and personnel, to arrange the office efficiently, to develop forms and standard procedures, to institute machine operations, to prepare a budget, to develop communication systems, and to maintain distribution records. The astute manager, today, must be thinking and planning in terms of the future supply and demand.

The importance of the matter of supply and demand is shown by the charts herewith. These charts were prepared by the Water & Sewage Industry & Utilities Division; BDSA, U. S. Dept. of Commerce. The charts were distributed by the Amer. Water Works Assn. with the timely heading, "WAKE UP WATER WORKS—See What's Happening!"

AWWA added these comments: "Water use is increasing more rapidly than population"—"The Public Wants Service!"—"Water Works Must Meet the Needs!"

These charts bear repeated consideration and study. Each water utility should apply the same criteria to its own facilities and do some constructive planning for the future.



Meeting Air-conditioning Growth*

by C. K. MATHEWS

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THE necessity or desirability of conserving water used in air conditioning is considered differently by the water consumer, the utility, and the city. The consumer is concerned directly only if his individual costs are affected. The water utility is concerned when the capacity of its facilities or source of supply may be exceeded. The city, apart from being the owner of the water utility, is concerned, as a proprietor, with the effect on storm and sanitary sewers and on sewage treatment plants.

TABLE 1
Factory Shipments of Room Air Conditioners*

Year	No. of Units	Retail Value $1,000,000
1947	42,900	20
1948	76,500	33
1949	95,500	39
1950	195,000	72
1951	237,500	87
1952	341,000	123

*Data quoted in Reference No. 1.

Why should air conditioning be considered specially, instead of merely as another possible use for water? The answer is twofold: first, there has been a tremendous increase in consumer demand for air conditioning since World War II; and, second, water use in nonconserved air conditioning has an abnormally poor annual load factor. An air-conditioning installation provided with conservation equipment requires a relatively small quantity of water per day (about 5 per cent of that required for a nonconserved unit) and is, therefore, only another normal service.

The term "nonconserved air conditioning," as used in this paper, refers to equipment that passes condenser cooling water only once through the unit and then wastes it to the sewer. "Conserved air conditioning" refers to installations in which a cooling tower or evaporative condenser is provided for cooling and recirculating the water. The quantity of water actually passing the condenser amounts to perhaps only 2 gpm per ton for the nonconserved equipment as against approximately 3 gpm for the conserved equipment. In the latter, however, the water is reused, with a makeup of approximately 2 per cent of 3 gpm, or 0.06 gym. On the average, the water requirements during the maximum day will be 1,150 gpd per ton of nonconserved air conditioning, against 57 gpd per ton of conserved air conditioning. Available data indicate that about 10,000 cu ft of water per ton per season will be used with nonconserved equipment. Actual usage will, of course, vary with the weather. In a 122-day season, approximately 8.1 mil gal will be used per 1,000 tons of nonconserved equipment for each 1,000 degree-hours above 80°F.

The rise in consumer demand for air conditioning is indicated by Table 1. The figures include window and console models (up to 2 tons in capacity) which are air cooled and do not, in themselves, affect water demand. The full year-round air conditioning of homes with central station residential units is, however, of tremendous concern to the water utility. Past and projected sales of such units are shown in Table 2. They will range in capacity from 2 to 10 tons or more, and most of them will probably be water cooled. Air-cooled units are at present available up to 5-ton capacity, but they are usually uneconomical.

All important commercial buildings will ultimately have to be air conditioned for competitive reasons. It has been estimated[1] that, when 15 per cent of the desirable office space in any city is air conditioned, this service becomes a competitive necessity for all other buildings in the city.

TABLE 2
Sales of Year-round Residential Air-conditioning Systems

Year	No. of Systems
1946	0
1947	100
1948	200
1949	300
1950	1,400
1951	3,000
1952	10,000
1953	60,000
1954	120,000
1955	240,000
1956	360,000
1957	540,000
1958	700,000

The number of industries dependent to some degree upon air conditioning is steadily growing. The list now includes: ammunition, candy and confectioners, cereal and food products, film, leather, paper, pharmaceuticals, plastics, printing and lithography, textiles, tobacco, aircraft components, cameras, communications, electronics, optical goods, vitreous ware, precision equipment, blast furnaces, dye works, explosives, gases, heavy chemicals, rayon, rubber, antibiotics, bakeries, biologicals, breweries, distilleries, and meat packing. There is also another large group of industries, such as those involved with petroleum chemicals, in which cooling or refrigeration is required as part of the manufacturing process.

These statistics indicate without question that, at least in the next 10-year period, demands for water for

TABLE 3
Air-conditioning Demand, Kansas City, Mo.

Year	Air Conditioning tons	Max. Day Demand—mil gal		Air-conditioning Max.-Day Demand % of total
		Air Conditioning	Total (All Uses)	
1942	21,089	12.7	84.5	15.1
1943	21,721	13.1	73.7	17.8
1944	21,927	13.2	78.9	16.7
1945	22,092	13.3	85.6	15.6
1946	22,537	13.6	86.8	15.7
1947	24,324	14.7	95.1	15.4
1948	28,261	17.1	103.5	16.5
1949	35,316	21.4	101.5	21.0
1950	41,332	25.1	109.7	22.8
1951	42,000	25.4	97.8	26.0
1952	44,520	27.0	105.9	25.5
1953		29.0	129.8	22.5

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TABLE 4
Load Factor, Kansas City, Mo.

Class of Service	Demand—mgd Max. Day	Avg. Day	Ratio
Entire system	104.7	59.0	1.78
Inside city	87.8	45.5	1.93
Suburban	11.0	8.8	1.25
Industrial (3 large industries)	5.9	4.6	1.28
Residential	30.7	18.7	1.64
Commercial (including air conditioning)	51.6	26.8	1.92
Nonconserved air conditioning	**24.2**	**4.3**	**5.62**
Other commercial	27.4	22.6	1.21

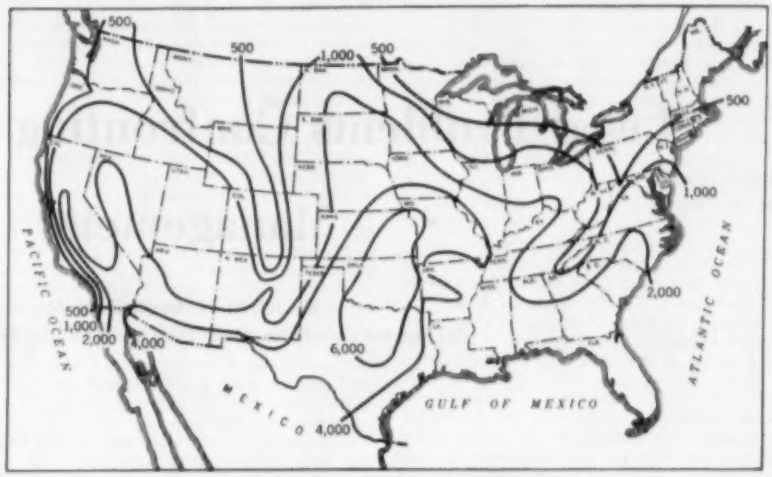

Fig. 1. Annual cooling requirements
Values are in "degree-hours" above 85°F.[2]

air conditioning will increase very rapidly. If the water used is not conserved, the quantity required from the utility during the summer days will frequently overtax available facilities, even if steps are immediately taken to provide additional capacity. The effect will be greater in some portions of the United States—particularly the central states—than in others, depending on temperature and relative humidity (see Fig. 1).

The progressive effect of air-conditioning water requirements on the day of maximum demand at Kansas City, Mo., is indicated in Table 3. It will be seen that the maximum daily demand for air-conditioning water in 1953 was 22.5 per cent of the total maximum-day demand. Available data for Kansas City, Kan., indicate that only about 7 per cent of the maximum daily demand is for air conditioning. The comparable figure for Omaha, Neb., is 10.6 per cent. The lower percentages in these two cities reflect the fact that a considerable proportion of the system usage is attributable to large industrial customers. It is important to note, however, that, in all three cities, a reserve of several million gallons per day of plant and system capacity is required to meet the seasonal demand of nonconserved air conditioning.

The extreme seasonal character of nonconserved air conditioning is best indicated by the poor annual "load factor" of this service. The ratio of maximum-day to average-day demand at Kansas City, Mo., is shown in Table 4. As the maximum-day rate determines the size of the treatment plant and other facilities, these data indicate conclusively that nonconserved air-conditioning water is much more costly per gallon than water for other services. Calculations for Kansas City show that the cost of the former is 28 cents per 100 cu ft, as compared with approximately 10 cents for other commercial and industrial uses. If rate schedules reflected this differential, there would be no question of the economy of employing conservation equipment, except, perhaps, in older buildings, where the expense and inconvenience of installing the necessary plumbing might be excessive. The comparative economy of cooling-tower conservation versus nonconserved use of city water at 20 cents per 100 cu ft is shown in Table 5. At this price for water, conservation equipment is economical even for small installations. Such a charge, although not intended as a penalty, would have the same effect as an outright restriction or a regulation requiring conservation equipment.

If the source of supply is inadequate, the obvious solution is to prohibit nonconserved air conditioning by ordinance. A model ordinance of this type has been published as part of an AWWA committee report.[3]

The establishment of a rate schedule to include proper charges for nonconserved air-conditioning service is politically difficult, especially when the existing schedule provides a decreasing charge as the quantity used increases. Likewise, a restrictive ordinance is unpopular, because "the free use of water is to be encouraged" and "the utility is in business to sell water." The alternative procedures—to restrict the use of water for lawn sprinkling on hot summer days or to raise large amounts of money to build more utility plant—are also politically inexpedient. The problem is too serious, however, to be ignored merely because the measures for dealing with it may be disagreeable.

TABLE 5
Annual Costs of Conserved and Nonconserved Air Conditioning*

Size of Unit tons	Cooling-Tower Installed $	Depreciation (10%) $	Maintenance (3%) $	Power for Fan and Pump† $	Makeup Water‡ $	Total Operating Cost $	Nonconserved Water§ $	Saving $
2	400	40	12	12	3	67	96	28
3	500	50	15	17	4	86	144	58
5	650	65	19	22	7	113	240	127
7½	800	80	24	30	11	145	360	215
10	1,000	100	30	35	14	179	480	301
15	1,450	145	43	50	22	260	720	460
20	1,850	185	55	65	29	334	960	626
25	2,200	220	66	85	36	407	1,200	793
35	2,500	250	75	100	50	475	1,680	1,205
50	2,800	280	84	125	72	561	2,400	1,839

* Assuming 1,500 hr of operation per year at temperatures varying from 78° to 95°F and averaging 85°F; water charge, 20 cents per 100 cu ft.
† Based on 2.5 cents per kilowatt-hour for 2-25 ton sizes, and 2 cents for 35- and 50-ton sizes.
‡ At 2 per cent of 3 gpm per ton.
§ At 2 gpm per ton.

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3. Committee Report. Regulation of Air Conditioning and Other Refrigeration. *Jour. AWWA*, 42: 1111 (Dec. 1950).

Legal Problems Confronting Water Works Management*

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TO keep this paper within tolerable length, consideration of many interesting legal problems must be omitted entirely and the answers to some of those studied must be indicated by statements of general legal principles applicable to a wide variety of factual situations. Two subjects will be discussed [1] water works liability for damages caused by negligent operation; [2] weighing the public interest in water supply against property rights. Usually the term "water works" will be applied, without distinction, to both publicly and privately owned systems, and will mean an enterprise offering public water supply service.

Water Works Liability

In the law of negligence there are certain words and phrases which are used so often that a knowledge of their meaning is essential to an understanding of the statements of legal principles in which they are used. The first word to be defined is "negligence." Negligence is the failure to observe, for the protection of the interests of another person, that degree of care, precaution, and vigilance which the circumstances justly demand, whereby such other person suffers injury. Negligence is the absence or want of care which a reasonable man would exercise under the circumstances (*Maternia* v. *Pennsylvania Railroad* 358 Pa. 149). Any conduct which falls below the standard established by law for the protection of others against unreasonable risk of harm is negligence.

This definition of negligence in turn calls for a definition of the phrase "standard of conduct established by law." It means such course of conduct as would be followed by a reasonable man under like circumstances. Who is a reasonable man? He is a person exercising those qualities of attention, knowledge, intelligence, and judgment which society requires of its members for the protection of their own interests and the interests of others. Negligent conduct may be either: [1] a failure to do an act which is necessary for the protection or assistance of another and which the actor has a duty to do; or [2] an act which the actor as a reasonable man should realize involves an unreasonable risk of causing an invasion of an interest of another.

The last definition can be understood only if "unreasonable risk" is defined. It means a risk which outweighs the values attached to the conduct which involves it. "The operation of railways and other public utilities, no matter how carefully carried on, produces accidents which kill or harm many people, but the risk involved in the operation is more than counterbalanced by the service which they render to the public" (Restatement of the Law, Torts, Section 292). Because of this counterbalance in favor of the operation, it is not an unreasonable risk which is involved. On the other hand, driving a car at 50 mph through a business street during the rush hour on a mere pleasure trip would be conduct involving an unreasonable risk of harm to others. The pleasure trip at that time, place, and rate of speed does not have enough social value to counterbalance the dangers involved.

In theory it is probable that all conduct involves risk, but a reasonable man need weigh only those circumstances which he knows or should know at the time of his action. A reasonable man is not assumed to be all seeing, all knowing or clairvoyant. He need not refrain from conduct having social value because he fears there may be evil consequences traceable to elements in the circumstances which he does not know or could not know through the exercise of reasonable prudence.

Water Works Risks

In water works enterprises, the standard of conduct established by law is the course of conduct which would be recognized by good water works operators—considered as such by this Association—to be the course of action which should be followed by a fellow water works operator under the circumstances. A water works operator is negligent when he fails to act or when he acts in a way which does not measure up to what well-grounded, careful, considerate, but active water works operators think should be proper action. Particular attention is directed to the definition of unreasonable risk as "a risk which outweighs the value attached to the conduct which involves it."

Many water works operations involve elements of risk, but if the community considers that the social value of the operation outweighs the risk of harm, then water works operators are not guilty of imposing and unreasonable risk on others by carrying on those operations. The water works is liable for damages only if water works action caused the damage and if the action involved an unreasonable risk. Thus, a high-pressure water line in a business street may burst. There is, therefore, a risk in placing such a line in such a place, but the community needs that line in that street and the utility of having the line there—its social value—outweighs the risk of harm. The act of placing the lines does not impose an unreasonable risk. If, despite the fact that the line was properly installed and the pipe was of proper class for the conditions, it bursts and floods adjacent basements, there is no negligence and no liability for damages. On the other hand, if the line was improperly laid on an unsound and unstable foundation and injury is caused by a resulting break and flood, then damages could be collected because the lack of care in laying was an act which imposed an unreasonable risk and was not up to the standard of a reasonable man.

The same legal principles are involved in passing upon questions of liability in other features of water works enterprises. If a water works operator knows, or by the exercise of reasonable care should know, of dangerous conditions and fails to correct them, the water works would be liable for damages to one injured if the injury was caused by the dangerous condition. Broken, sunken, or protruding valve box or meter box covers are typical examples. Slight irregularities in a pavement resulting from such box covers can probably never be avoided, and would probably be held not to impose an unreasonable risk on pedestrians or drivers, but an irregularity which is so pronounced as to make injuries a probability and which has existed for a substantial length of time so that the water works men should have seen it and repaired it, would impose an unreasonable risk.

Connections between a public potable water supply and a nonpotable supply on the premises of a customer, or interior plumbing conditions or practices making back-siphonage of contamination into the public water system a possibility is a controversial point. If a waterborne disease developed as a result of such a condition, would the water works be liable? The point is controversial because some state departments of health seem to feel that the water works should assume the responsibility of making inspections of consumers' premises to discover and correct such dangerous con-

*Reprinted from J.A.W.W.A., Vol. 44, p. 1085 by permission of the Association.

ditions, whereas some water works officials feel that they have no responsibility beyond the service connection. In other words, there is controversy about what a resonable man should do under the circumstances. Inasmuch as the author has, on other occasions, failed to agree with either of these positions, he has been subjected to fire from both sides. It is his opinion today—as it was years ago—that the conduct of a reasonable man would be to use ordinary intelligence, and, when such intelligence told him dangerous conditions existed, force correction or discontinue service. On the other hand, the author does not believe that the water works should allow the public to think that it polices the premises of its consumers, thus making itself liable for damages resulting from conditions of which it had no adequate means of learning.

A water works must, at its peril, furnish water which is safe for domestic use. It is also required by regulatory bodies and the courts to supply a water which is reasonably free of turbidity, color, taste and odor —that is, it must do the best it can in these respects, considering all the circumstances. It is not required to do what is practically impossible, and some variations in quality due to emergencies or drought are not normally considered evidence of poor management. The water works is not expected to deliver to all of its customers water of a particular character needed by some one or more of its customers. Thus, if a manufacturer requires water free from all color or having some other special characteristic not demanded by the customers in general, failure to furnish this special type of water would not be grounds for legal action. Once the manufacturer was led to expect and rely on the water works furnishing such water, however, a reasonable man would notify the manufacturer, if possible, before a change in water quality took place in order to enable him to avoid loss.

Fluoridation

From the standpoint of a lawyer, the problems involved in flouridation are problems which come under the law of negligence. For the purposes of this discussion, it is assumed that the community has taken all appropriate action to indicate a desire for fluoridation and that the equipment and methods to be employed have been approved by the proper health authorities. It is also assumed that the general community recognizes that the addition of fluorides to the public water suply in the indicated amounts will probably result in some significant increase in tooth mottling. It is assumed that in addition to this recognition, there is the belief that the program will result in a substantial reduction in tooth decay, at least among the children, and that there are good prospects that the benefits to the children will carry over into their adult life. It is also assumed that the water works operator and the public know that continued overdosage of the water for a long period would cause a serious and distressing increase of tooth mottling, but that no known adverse side effects are to be anticipated from the program if only proper quantities are added to the water. It is assumed that the public health scientists have established these points to their satisfaction and that their findings have been published and not successfully attacked.

Under these conditions, it is clear that the water works operator is acting as a reasonable man would, and is not exposing his customers to an unreasonable risk when he undertakes to carry out the program as planned. The community has weighed the social advantages of reduction of tooth decay against the risk of some increase in tooth mottling and has chosen fluoridation. Those who suffer tooth mottling as part of the small group so affected would have no right of action against the water works—they had not been subjected to an unreasonable risk. If a very large proportion of the people developed mottled teeth after the program was put into effect, the experts would be justined in the opinion that the water works had been negligent over a long period of time and had put excessive quantities of fluorides into the water. The water works manager knew the danger and knew that the risk of such a result was not outweighed, in the minds of the community, by the reduction in decay; therefore, the water works would be subject to damages. The water works would be found to have acted negligently in permitting the excessive dosage over a long period. The excessive dosage, not the engaging in the approved program, imposed the unreasonable risk on the community. In view of the assumed scientific determination that the experienced results would not come about except after continued overdosage for a long period, the courts would probably say that negligence was the only inference that could reasonably and legitimately be drawn from the circumstances. The doctrine of "res ipsa loquitur" ("the thing speaks for itself") would aply and the time, place, and manner of the negligent acts would not have to be proved.

There would, however, be no liability if an entirely unforeseen adverse side effect developed, because an actor is only responsible for failure to consider circumstances which he knows or should know. The water works operator had no means of knowing that these side effects would develop. Therefore, he was not negligent. To a lawyer the fear of successful suits for damages based on such unforeseen side effects seems groundless.

Public Interest and Property Rights

Two recent cases involving water works should be mentioned because, in deciding them, the courts applied legal principles which water works managers should know. The first case was decided by the Supreme Court of Errors of Connecticut at its June term, 1951, and the second by the Court of Appeals of Kentucky on Mar. 28, 1952, as extended on denial of rehearsing on June 20, 1952.

In the Connecticut case the Greenwich Water Co. held a statutory right to take water from the Mianus River but this statutory right was subject to the riparian rights of owners of property along the river. That is, the water company had no legal right to divert the water of the river —as against those riparian owners—without purchasing or condemning the riparian rights. The majority of those riparian owners purchased, improved, and maintained their properties as country estates, counting on the river as one of the attractive features. Aside from swimming, use of water from the river for lawn and garden sprinkling, watering of chickens, and domestic sanitary needs, the owners valued the water for its enhancement of the beauty of their estates. The water company had not acquired the riparian rights. In 1949, a long period of severe drought began and the normal sources of supply for the company were either cut off or so reduced that emergency conditions for the community developed. By pumping some of the flow of the Mianus River, the company was able to maintain some service. Under these circumstances, a group of influential riparian owners went into court seeking an injunction to restrain the company from diverting any of the waters of the stream. (It is interesting to note that the trial court found as a fact that "a water company in the situation of the defendant should plan for a supply of water to meet conditions as they will be at least ten and preferably fifteen or twenty years in the future.") The trial court refused to restrain the pumping from the river and the riparian owners appealed.

The Supreme Court of Errors in its opinion stated:

The diversion of the water was without any claim of right, was wilful and, *except for the consideration of the public interest* . . . was inexcusable. . . . It is well within the court's discretion to deny an injunction against the infringement of riparian rights if to grant it would *adversely affect the interest of the public*. . . . Under the circumstances . . . equity demanded that the defendant be allowed a reasonable time within which to make adequate compensation to the plaintiffs for the permanent taking of their water rights if it intends to acquire them, and, if that compensation is not made within such reasonable time, the defendant should be enjoined from further diversion of the waters of the stream. [Author's italics.]

In short, the court held that the temporary emergency invasion of the property rights of the riparian owners should not be restrained where such restraint would adversely affect the interest of the public. Water works managers must never forget the public interest—the public nature—of their work.

The second case is *Daugherty v. City of Lexington*, et al., 249 S.W. 2nd, 755. The opinion of the Court of Appeals of Kentucky, as extended on denial of rehearing, was delivered June 20, 1952. The case involved some very complicated questions on statutory law regarding zoning and even more complicated questions of pleading and practice, but none of these questions is of particular interest to water works managers. The point which is of great interest is the court's attitude toward a property owner's plan to develop his own property in such a way as to endanger a source of public water supply.

Daugherty sought a permit from the board of adjustment of Fayette County for the erection of a restaurant, gasoline station, and tourist cabins on his property, which was 1,100 ft. from the reservoir of the Lexington Water Co. The elevation of Daugherty's property is between 20 and 30 ft. above the water elevation of the lake. Daugherty proposed to care for the wastes from his development with two separate septic tanks, one of 1,000-gal. capacity and the other of 500-gal. capacity, each draining into a separate septic field of drain tile in crushed rock fill. The board of adjustment denied the permit because the proposed methods for water supply and disposal of sanitary waste had not been approved by the county health officer. That officer refused to approve those plans, saying that he thought only in terms of public health and safety and the topography of land in the proposed area. Daugherty contended that his proposed method of sewage disposal is completely adequate, modern, and as satisfactory and safe as it is reasonably possible to obtain; that it will cause no health hazard to the public generally; that the proposed use of his property constitutes a reasonable and natural use; and that to prevent him from so using his property, in order to protect the purity of the water in the reservoir lying below his land, amounts to a taking of his property without just compensation, not for the benefit of the

public generally but for the benefit of a private corporation. His pleadings did not allege that his disposal system would not endanger the purity of the water in the reservoir.

The point at issue on the aspect of the case in which water works operators are interested may be paraphrased from the court's opinion. Did the health officer and the board of adjustment act arbitrarily and unreasonably and with the sole purpose of protecting the private property of the Lexington Water Company? In answer, the Court of Appeals decided the case against the property owner and, in the opinion, made some very interesting and important points, which follow:

The water company is in substance nothing more than a management corporation, allowed to make a reasonable profit for furnishing water to the city.

The public has a direct interest in the preservation of the purity of the water in the reservoir of the Lexington Water Co. So Daugherty's right to convert his property to a commercial use must be measured against this public interest in determining this question of reasonableness.

He may not use his property in such manner as will endanger the source to which the public must look for its supply of water. [Author's italics.]

This case indicates that a property owner not only has no right to contaminate a public water supply but has no right even to endanger it. The burden is on the property owner to prove that his proposed use will not endanger the purity of the water in a public supply. No longer, under this sound doctrine, will water works be compelled to wait until the purity of supply has been destroyed before taking action. The public interest comes first. The Kentucky decision is in line with, but in a sense a further development of, a doctrine announced in many other jurisdictions.

Other Court Decisions

Two older cases in Pennsylvania may be cited as fairly typical. In *Commonwealth* ex rel. *and Butler Water Co.* v. *Russell* et al, 172 Pa. 506, the Supreme Court of Pennsylvania reversed a decree of the lower ocurt against the commonwealth and the water company and sent thé case back for full hearing on the facts. The appellate court opinion suggested certain questions to be considered after the facts had been developed. It said one question was: "whether in other words, the Commonwealth, in the exercise of its police power, may not limit and restrict the individual in the exercise of admitted rights, when the welfare of the public requries it; or whether it is indeed true that the ownership of a few acres of land, or a leasehold interest therein, gives to the holder an unqualified right to destroy the water supply of a city. . . ." The court did not answer these questions directly but its thinking was indicated and was well understood. In *Pennsylvania Railroad* et al. v. *Sagamore Coal Co.* et al., 281 Pa. 233 (Cert. denied 267 U.S. 592) the Pennsylvania Supreme Court, in effect, gave direct answer to the questions suggested in the Butler case. In the opinion it was said, "It has always been under our law a nuisance to pollute a stream from which the public gets its supply of water. . . . There could not be such a thing in the law as a property right to do a wrong. . . . Our conclusion is that defendants have no right of any kind to drain their mine waters into the stream considering the public use which is made of its waters and that their doing so constitutes a nuisance which must be restrained."

There is no such thing as a property right to pollute a public water supply. Even to endanger such a supply may be restrained by the police power of the state and the affected landowner need not be compensated.

Other Problems

Only a very few of the legal problems of water works managers have been touched upon. The legal problems involved in keeping water works enterprises—both publicly and privately owned—financially strong enough to give the type of water service which the communities really need are the most pressing problems which face water works managers. Discussion of these problems would require much space and so must be omitted. The impact of inflation on all water works operations when courts and regulatory bodies tend to give predominant weight to original cost deserves the careful attention of the water works man. If rates are based, in effect on the average net investment in utility plant and property, those rates must be adjusted upward very frequently. Otherwise new customers become a burden, because the increase in net plant and property per added customer goes up each year of inflation and is usually at least double the average investment per customer at any time. Furthermore, consideration might well be given by water works men to the legal problem of determining a fair rate of return. Is a rate fair which is merely equivalent to the rate of return now demanded by new investors who put in the presently devaluated dollars, if it is to be applied to existing investors in common stocks who put in the old-time, "100-cent" dollars? The older investor's ability to buy bread is lessened although he may have the same number of dollars. Wage earners get more dollars now than they did before inflation. Why not give the holder of common stocks of water companies the same hedge against inflation?

WHERE THE WATER DOLLAR GOES

Here is an interesting and enlightening chart taken from the 22nd Annual Report of the Water Department, Springfield, Ill.

It is based on a survey made by H. V. Pedersen, Water Supt., at Marshalltown, Iowa, to determine what percentage of water in the average consumer's home goes for various uses.

The Springfield folks have taken these percentages and made them more real to the customer, by showing him that out of every dollar paid for water used it only cost him 1 cent to wash his car, only 4 cents for laundry work at home, 3 cents for sprinkling in summer.

Industrywide Safety Program*

by RAYMOND J. FAUST

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IN 1951 an AWWA task group (*1*) reporting its findings on safety practices in the water industry concluded that:

1. With some notable exceptions, the water works industry is not safety conscious.

2. The frequency rate of disabling injuries in water utilities in 1949, as reported by the National Safety Council, was 33. This figure compares rather unfavorably with the other utilities: gas 17; electrical, 14; and communications, 2.

3. The accident severity rate for the water works industry for 1949 . . . was approximately equal to the national average for all industries.

It must be understood that the water industry figures were based on conditions in only 33 utilities, less than 0.2 per cent of the total of 17,000 operating units involved. Although the figures represent only a minute segment of the water industry, they depict the situation at its best, for it may be presumed that the experience in water works not even safety conscious enough to keep records was worse than in the few utilities with established programs.

The task group report also indicated that the lack of a safety program was not confined to small utilities. For example, a questionnaire survey of 153 towns showed that 5 of 14 water utilities serving more than 500,000 people reported having no safety program in 1951; the same was true of 27 of 49 utilities in the 100,000-500,000 group, 42 of 69 in the 30,000-100,000 group, and 15 of 21 in the 10,000-30,000 group. This analysis gives a representative view of the extent of safety practice in the industry in 1951, with one major exception: the questionnaire did not include the water utilities serving a population of less than 10,000, which comprise the great majority of plants. It is known, however, that the practice of safety in these small plants is virtually nonexistent. Thus, it was apparent in 1951 that a real selling job was needed to establish an adequate safety program for the industry.

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Obstacles to Program

A consideration of the size, organization, and financial aspects of the water industry may reveal why it has lagged behind other utilities in adopting a safety program. The number of water utilities in the United States is almost twice the total of gas, electric, and communications utilities combined. The promotional effort needed to establish a safety program at every water works is, therefore, very much greater than that required for other utilities.

Furthermore, 99.3 per cent of the 17,000 water utilities may be classified as small businesses, because they serve towns with less than 100,000 people and have an operating force of between one and 100 employees each. In fact, 93 per cent of the water utilities —that is, almost 16,000 units—may be classified as very small businesses, because they serve towns with less than 10,000 people and employ one to ten employees each. These figures become significant when it is realized that small businesses generally have been slow in adopting safety programs and that two-thirds of all industrial injuries occur in businesses with fewer than 100 workers. Thus, by itself, this great preponderance of small operating units largely explains the present position of safety in the industry. So-called big business in the industry comprises only 0.7 per cent of all water utilities; only 93 organizations employ 100 or more (up to 3,000) persons.

Another fact of importance is that 70 per cent of the water utilities, numbering approximately 12,000, are owned publicly and locally and operate without outside direction or help. In theory, each utility's administrative structure should include separate divisions for treatment, pumping, distribution, meters, transportation, commercial activities, engineering, management, and safety. In the vast majority of utilities, however, this number of divisions is greater than the number of employees. Obviously so elaborate an organizational setup is out of the question. In many small publicly owned water utilities, one man takes care of all divisions and, in addition, is chief of police and superintendent of streets, sewers, and parks, while, in his spare time, he acts as truant officer. It should be apparent that, in these circumstances, only what is immediately necessary will get done. Such refinements as safety are inherently abstract considerations, and a formal safety program has little chance of being established or maintained.

Finally, water utility personnel generally are underpaid. The result is that the industry fares poorly in bidding for the more highly skilled and trained personnel. Under this added handicap, new ideas or programs are not readily assimilated into an already underdeveloped organizational structure.

Safety Campaign

Despite these difficulties, the safety problem is being intensively attacked. In 1950, at the urging of Wendell R. LaDue, Chief Engr. and Supt., Bureau of Water and Sewerage, Akron, Ohio, and Chairman, AWWA Committee on Water Works Administration, the AWWA Board of Directors approved the appointment of a task group to study and report on the status of safety in the industry. Published in 1951, the report (*1*) pointed out not only the need for the application of safety practices in the industry but also the advisability of a more detailed study. The latter was accomplished by setting up four task groups, assigned respectively to study safety as it applies to: [1] supply; [2] treatment and pumping; [3] distribution; and [4] administration. A report on these studies appeared in 1953 (*2*).

With interest in safety accelerating among AWWA members, the Board of Directors, in 1953, approved the preparation of a water works safety manual. The four task groups were united in this effort in a 16-man committee to do the job. The first rough draft of the text has already been prepared, and the document is scheduled for completion by the end of 1954. [When the manual becomes available, notice will, of course, appear in the JOURNAL.] The manual will be fully illustrated, with photographs and sketches covering almost every work assignment in the industry. It is expected that it will be especially helpful in promoting the adoption of safety programs in the small utilities, as well

as in teaching the practice of safety.

Both the JOURNAL and *Willing Water* have carried many papers and stories on the practice of safety during the past three years. These articles tend to keep the subject before the utility operators and point out what can be and is being accomplished. An example of an excellent safety performance in the industry is the record made by the 232 employees of the Akron water utility in 1952. Only one lost-time accident was suffered in 447,095 hours of work. For this outstanding achievement, the National Safety Council presented Akron with an award of honor. A description of the Akron program has been published previously (*2*).

Another safety program which has met with considerable success is that of the Kansas City, Mo., Water Dept. (*3*). In August 1951 the department took its first step toward establishing such a program. Results were not long delayed. A check of the records showed that the cost of carelessness to the department was $4,360 for the period March-September 1952, compared with $16,473 for the same period in 1951. These costs include: wages paid to injured employees while they were not working because of their injuries; doctor and hospital bills; and settlement of claims for injuries and damage to property. In six months, $12,113 was saved on these items, all of which are directly affected by a safety program. Success stories of this type are proof that an effective safety program is possible in the water industry. Many of the AWWA sections have established safety practice committees to study the problem regionally. The sections are also scheduling papers and panel discussions on safety at their annual meetings. Thus, the program is spreading to the local levels, where it can be sold most readily to the superintendents.

Conclusion

To date, the results of efforts to establish safety programs in the industry have been encouraging. The enthusiasm developed by many members of the industry has given the AWWA safety practice committee reason to believe that the program is gathering momentum. The job of winning over the operators of small plants, however, is still to be done. To accomplish it, a strong and well directed educational campaign is necessary. Fortunately, the water industry has many short-course schools available to carry out this assignment. These schools were established years ago, principally by the state departments of health, to teach water plant operators the skills needed for the treatment and quality control of public water supplies. It took at least 40 years to disseminate the technical knowledge that has made water-borne diseases largely a thing of the past. The objective of a safe work environment at every water plant should not take nearly so long to achieve as did the objective of making all supplies bacteriologically safe. With the advantages of an established educational system, a strong national association, and the will to succeed in making the employees' environment as safe as the water they produce, the difficulties of realizing an industrywide safety program can and will be overcome.

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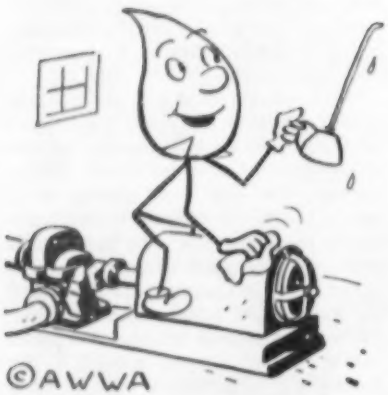


Safe Practices in Chlorine Handling

From a Report
by
THE JOINT COMMITTEE ON CHLORINE SUPPLY

IT IS ESSENTIAL for persons responsible for the handling and application of chlorine at any installation to have a relatively comprehensive knowledge of the characteristics and properties of chlorine.

GENERAL RECOMMENDATIONS:

1. Only reliable men whose training in the handling of chlorine is commensurate with their responsibilities should be permitted to handle chlorine.

2. Chlorine and chlorinator rooms should be provided with adequate ventilation. In large installations, subsurface installations, or in buildings occupied by persons or containing equipment subject to chlorine attack, a separate and reasonably gas-tight room, equipped with mechanical ventilation which will change the air twice every minute, is considered essential and is required by some local and state regulations. Exhaust duct ports should be at floor level and ducts should terminate through a completely separate exhaust system to a location high enough to insure atmospheric dilution without endangering personnel or adversely affecting property in the area. Air inlets should be located across the room from exhaust ports, with the air of such temperature that it will not affect the chlorination equipment adversely.

Shutoff valves should be provided near chlorinators if the connected chlorine containers are in a separate room or a considerable distance from the chlorinators. Switches for fans and lights should be outside the room, at the entrance. The vent hose for the chlorinator should discharge to the outside atmosphere, above grade.

3. A suitable number of gas masks of types approved by the United States Bureau of Mines for chlorine should be provided and persons employed in the handling of chlorine should be trained in the use and maintenance of the masks. Gas masks should be located outside the probable area of contamination so that it will be possible to reach them in case of emergency. Where chlorine is used over wide areas masks should be available in several locations.

4. To test for chlorine leaks. Attach a cloth to one end of a stick, soak the cloth with ammonia-water, and apply to the suspected area. A white cloud of ammonium chloride will result if there is any leakage.

5. As soon as there is any indication of the presence of chlorine in the air, steps should be taken to correct the condition. Chlorine leaks always get worse if they are not corrected promptly. Solvay Emergency Devices, Kits "A," "B" or "C" should be available for stopping leaks in chlorine containers and men should be trained in the use of such emergency equipment. Telephone your chlorine supplier or any chlorine producer if you need help. Always wear a gas mask when correcting chlorine leaks. If a chlorine container is leaking in such a position that chlorine is escaping as liquid, the container should be turned so that chlorine gas escapes. The quantity of chlorine escaping from a gas leak is about one-fifteenth the amount that escapes from a liquid leak through the same size hole. At regular points of storage and use, emergency preparations should be made for disposing of chlorine from leaking cylinders or ton containers. Chlorine may be absorbed in caustic soda, soda ash, or hydrated lime solution. Caustic soda is recommended as it absorbs chlorine most readily. The proportions of alkali and water preferred for this purpose are given in the following table:

RECOMMENDED ALKALINE SOLUTIONS FOR ABSORBING CHLORINE

Chlorine Container Lbs. Nal	Caustic Soda Lbs. Chem.	Caustic Soda Gals. Water	Soda Ash Lbs. Chem.	Soda Ash Gals. Water	Hydr. Lime* Lbs. Chem.	Hydr. Lime* Gals. Water
100	125	40	300	100	125	125
150	188	60	450	150	188	188
2000	2500	800	6000	2000	2500	2500

* Hydrated lime suspension must be continuously agitated with vigor while chlorine is being absorbed.

6. Containers should be stored at a moderate temperature. Flames or direct heat should never be applied to a container. Chlorine containers connected to apparaus should be protected from a temperature higher than that of the equipment. When a number of containers are connected to the same manifold, chlorine may go from the warmer containers to the colder ones, which could result in filling some above the safe limit. The heating of containers involves danger because the fusible plugs are designed to soften or melt at a temperature between 158° and 165°F. At temperatures above 180°F, dry chlorine will attack the steel of the cylinders.

7. Avoid dropping or bumping chlorine containers. Containers should be securely fastened to prevent tipping or rolling.

8. Valve protection hoods on clyinder and ton containers should always be kept in place except when such are being emptied. Never hoist cylinders by the hood.

9. Keep valves of cylinders and ton containers closed at all times when not in service.

10. Store full and empty cylinders and ton containers in different places to avoid confusion. It is good practice to tag empties.

11. Put cylinders or ton containers in service in the order in which they are received. Cylinders and ton containers in active use should be located on a scale, so that the operator may know at all times the amount of chlorine in the cylinder or ton container, and also for purpose of recording chlorine used.

12. Use nothing but approved fitting for connecting chlorine containers. Never use pipe fittings on chlorine valves.

13. The following first aid measures are recommended for persons exposed to chlorine:

First Aid, 1. Carry patient from gas area. Patient should preferably be kept in a warm room (about 70 degrees Fahrenheit). Supply blankets if necessary. Keep patient warm and quiet. Rest is essential.

First Aid, 2. Place patient on back with head and back elevated.

First Aid, 3. *Call a physician immediately.*

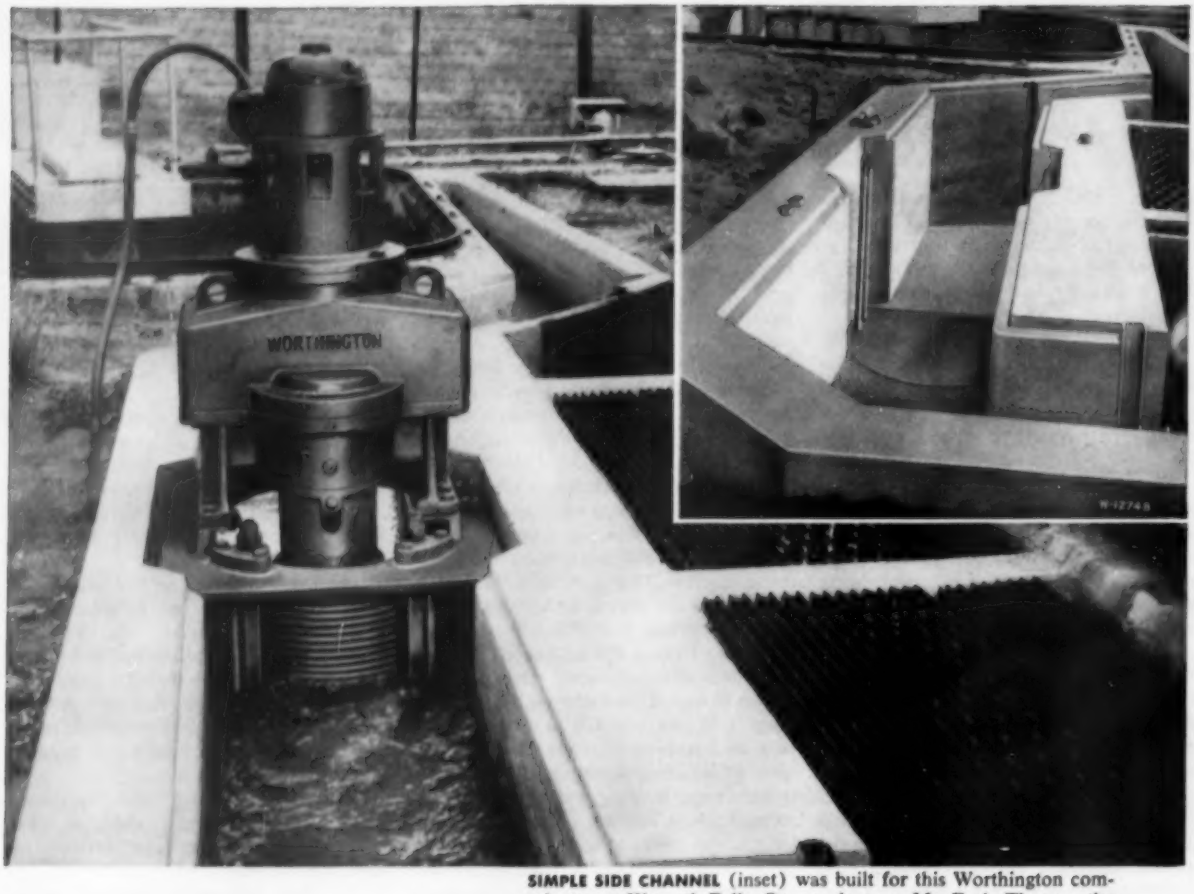
First Aid, 4. Splashes of liquid chlorine and chlorinated water destroy clothing, and if such clothing is next to the skin will provide irritation and acid burns. In such cases remove clothes and keep patient warm with blankets.

First Aid, 5. A carbon dioxide and oxygen mixture with not to exceed 7 per cent of carbon dioxide may be given. This mixture, ready prepared, and sold with the necessary apparatus, can be administered intermittently for periods of two minutes followed by two-minute rest periods over a total period not to exceed thirty minutes. Instructions of the purveyor of the gas apparatus should be carefully followed. If a carbon dioxide and oxygen mixture is not readily available, oxygen alone may be used.

First Aid, 6. Milk may be given in mild cases as a relief from throat irritation.

First Aid, 7. If breathing has apparently ceased, start immediately the back pressure-arm lift method of resuscitation.

First Aid, 8. Provide First Aid as may have been prescribed by the physician pending his arrival.



SIMPLE SIDE CHANNEL (inset) was built for this Worthington comminutor at Klamath Falls, Oregon, because Mr. E. A. Thomas, the City Engineer, wanted to use the existing channel as a by-pass.

Low installation cost swings Klamath Falls to Worthington

Since the Worthington comminutor is designed so that raw sewage flows straight through its screen, it's easily installed in a straight rectangular sewage channel.

Result? Expensive masonry work is not needed, which makes for simplified, low-cost installation.

This was an important factor in the selection of a Worthington 25C6 comminutor as part of recent improvements at the Klamath Falls, Oregon, Sewage Treatment Plant.

This comminutor, installed downstream from a grit chamber and upstream from a clarifier, was lifted directly from its packing crate and set right in the channel in a minimum of time.

Easy-to-remove cutter racks for occasional sharpening and the built-in flood protection provided by a mercury seal are other advantages of the Worthington comminutor.

Get all the facts and figures on the rugged Worthington comminutor. Check with your nearest Worthington district office. Or write today for new engineering manual on comminutors, W-317-B17. Worthington Corporation, Public Works Division, Harrison, N.J.

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IV. FUNCTIONAL OPERATIONS

IN THE FIELD of sanitary engineering, there are several operations which are fundamentally the same for water, sewage, or industrial waste treatment works. These operations, which may be termed functional, include: Pumping, Electricity, Flow Measurement, Instrumentation and Control, Chemical Handling and Feeding, Coagulation and Sedimentation, Corrosion Control, Laboratory Control, and Maintenance.

Pumping

Liquid will move from one point to a lower point under the influence of gravity, but will not move in the reverse direction without energy being expended to move it. Gravity flow is utilized in sewers and in some water distribution systems, but in most water works, pumps are required to provide the pressure necessary to deliver the water to the consumer's tap.

In sewage works, pump lift sewage from one sewer to a higher one, or from an interceptor to a treatment plant at a higher elevation. Pumps are also used to lift water from wells and to pump air, chemical solutions, sludge, gas, etc. The design of a pump will depend on the material to be handled, suction lift, discharge head, operating conditions and efficiency desired.

Electrical Equipment Operation

Today, most pumps are operated by electrical motors. Electricity also operates instruments, controls, signals, communications, chemical feeders, and lighting systems. Electricity, and its potentialities and properties, is necessary to the operation of any water, sewage or waste treatment facility. Equally important are electrical motors which operate pumps and other equipment.

Flow Measurement

Where volumes of liquids or other substances are moved from one point to another, it is desirable to know, not to guess, the quantity of material handled. Reasons for flow measurement include: To provide data and information on plant production; to provide information on operation efficiency; to control unit operations; to ascertain quantity of water sold or volume of sewage treated; to determine costs of operation; and to provide permanent records of operation.

Points of flow measurement should be set up wherever measurement of volume in motion will produce information to satisfy any of the reasons for flow measurement. The more completely metered a water or sewage plant, the better and more efficiently it can be operated.

Instrumentation and Control

Instruments, sometimes called receivers or secondary instruments, are devices which indicate, record or totalize some function of operation which is being measured. Flow, levels, pressure, loss of head, temperature, etc., are conditions of operation which may be shown or recorded on a secondary instrument. Indicators show conditions at the moment of observations, recorders give a permanent and continuous record on a chart showing conditions as they existed at any moment. Totalizers give a numerical summation, to the moment of observation, of quantities in motion.

Closely coupled with instrumentation is the matter of control. Control of flow, control of chemical feeding dosage, control of filter operations, control of treatment operations are all essential to proper operation of water, sewage or waste treatment facility. Control can be obtained by the use of devices which operate in conjunction with or in direct response to flow measuring devices and their secondary instruments or in conjunction with other operating devices and instruments. The high cost and weaknesses of manual operating procedures can be greatly reduced by the use of instrumentation and control.

Chemical Handling and Feeding

Whenever water, sewage or wastes require chemical treatment of any kind, the plant operator is faced with the problems of handling and storage of chemicals, and with adding the proper amounts of chemicals to produce the treatment desired.

Chemical handling begins with the receipt of a shipment of chemicals and ends with the introduction of the chemical into a chemical feeder. Chemical feeding involves the operation of a device to add controlled amounts of the chemical to definite volumes of liquid. Control of chemical dosage according to the needs of treatment and flow to be treated is accomplished by chemical feeders designed for the purpose and controlled by a flow measuring device, or manually. Different types of chemical feeders are designed to feed solids, liquids or solutions, and gases. The selection of chemical feeders depends on a study of type of installation, treatment required, chemical used, dosage range, control, etc.

Coagulation and Sedimentation

Removal of suspended solids is necessary in surface water supplies, water softening operations. This operation involves sedimentation, which may take place in rectangular or circular tanks, usually equipped with mechanical devices for the removal of the settled material.

Design of sedimentation tanks is related to rate of flow, rate of settling of particles, detention times and facilities for removal of solids. Operation is controlled according to loading, both as to liquid and solid volume.

When solids in a liquid are too fine to settle easily by themselves (i.e., bacteria, colloids, etc.), chemicals may be added to create flocs which will settle and sweep out the fine particles. Coagulation is controled by analysis of the liquid and the proper dosage of the coagulating chemicals.

Corrosion Control

Since water is almost a universal solvent, its presence creates the problem of corrosion. Under certain conditions almost all metals will corrode or be attacked, as will concrete. In many cases corrosion may become a serious problem in water or sewage works. It can be controlled or prevented in various ways. The control may involve protective coatings, or chemical treatment of the liquid to reduce its corosive properties.

Laboratory Control and Maintenance

While the actual laboratory tests made in water plants may differ from those in a sewage works, the fundamentals of analytical chemistry and bacteriology are used in the operation of a control laboratory. Laboratory control can improve plant operations and the quality of the effluent, and often reduce costs of operation.

Maintenance, particularly preventive maintenance, reduces operating costs, improves efficiency and lengthens the life of equipment.

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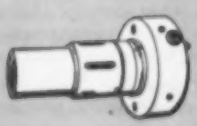

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PUMP DIVISION

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PUMPS AND PUMPING

A PUMP IS a mechanical device that will cause a fluid to flow, or to be discharged at a higher elevation or higher pressure. Power to operate pumps may be electricity, steam, internal combustion engines, waterfalls, or wind.

Reasons for Pumping

In a water works, pumps are used to:

- Lift water from a surface source of supply
- Lift water from wells
- Deliver water to consumers' taps at desired pressure
- Supply fire pressure
- Boost line pressure
- Fill elevated storage tanks
- Backwash filters
- Pump chemical solutions
- Dewater tanks, basins, sumps, etc.
- Provide boiler feed

In a sewage works, pumps are used to:

- Lift sewage from low areas to main sewers
- Lift sewage from interceptors to treatment plants
- Move sludge from settling tanks to disposal processes
- Recirculate sludge digestion tank contents
- Supply air to aeration processes
- Return activated sludge to process
- Provide digester tank gas to boilers or internal combustion engines
- Provide water for various uses including boiler feed and elutriation

Types of Pumps

Pumps may be classified by operating principle or by use. Operating principles include: Displacement, centrifugal, ejector, air lift, hydraulic ram and aorta.

Displacement pumps are a type in which water is caused to flow from the source of supply through an inlet pipe and valve into a chamber by a vacuum created by the withdrawal of a movable part, which on its return displaces the water in the chamber and forces it to flow through the discharge valve and pipe.

Displacement pumps are of two types: Reciprocating and rotary. In the reciprocating pump the movable part enters and withdraws from the chamber on the axis of the centerline of the chamber. Piston, plunger and diaphragm pumps operate on the reciprocating principle.

Rotary pumps consist essentially of a rotating element which fits closely in a case. The rotation alternately draws in and discharges water, with the discharge being opposite the suction. No valves are required and centrifugal force does not lift the water. Pumps which use the rotary displacement principle include: Gear, lobe, screw, Moyno, vane, and others.

Centrifugal pumps employ a rotating impeller, with water being drawn in at the hub or "eye" or the pump impeller and discharged through a spiral casing by virtue of centrifugal force developed by the rotation of the impeller.

True centrifugal pumps include the volute pump and the diffuser pump. In the volute pump the impeller discharges into a gradually increasing spiral case. In the diffuser centrifugal pump, the runner (impeller) is surrounded by gradually expanding passages formed by stationary guide vanes, which change the direction of the flow and increase pressure developed before discharging into a spiral casing.

Other pumps classed with the centrifugal pump, but not employing the centrifugal principle are the turbine pump, and the propellor or axial flow pump. The mixed flow pump develops its head partly by centrifugal force and partly by the lift of the vanes.

Pumps using other principles of operation are the ejector or jet pump, air lift pump, hydraulic ram and aorta pump. Jet and air lift pumps are used for deep well pumping; the hydraulic ram is used for small water supplies; the aorta pump is used for sampling or pumping small volumes of chemical solutions.

Uses of Pumps

Classified by use, pumps are called: Low Service, High Service, Deep Well, Booster, Sewage, Sludge, Boiler Feed, Chemical, Proportional Feeders, Air Blowers, etc.

Low service pumps operate at low discharge heads to lift water from sources of supply to water treatment works. High service pumps operate at high discharge heads to deliver water to distribution systems. Proportional feeders are used for dosage of solutions of chemicals or liquid chemicals; other uses listed are self-explanatory.

Selection of Pumps

Before a pump is selected for any use, it is desirable to be acquainted with pumping terminology and definitions. Such words as suction lift, discharge head, total dynamic head, specific speed, single stage, single suction, double suction, multiple-stage, split case, horizontal, vertical, and so forth are all important in the field of pumping.

In order to select a pump properly, it is necessary to have certain essential data on the pump installation. This information should include:

- Number of units required
- Nature of liquid
- Capacity
- Suction conditions
- Discharge conditions
- Total head
- Intermittent or continuous service
- Position of pump; horizontal or vertical
- Location, geographical, indoor, outdoor, elevation, etc.
- Type of power

Spacing of suction bells, methods of priming, size of suction and discharge pipes are other important factors in the selection and installation of pumps.

Pumping Station

Pumping stations or buildings to house pumps are usually necessary for both low and high service and booster pumps in water systems, as well as for sewage lift stations. Deep well pumps or motors may be housed or may not. Sewage sludge pumps are usually housed.

The architecture and surroundings of pumping stations of all kinds are generally designed to be attractive (both exterior and interior). This is in accord with the principles of good public relations to make the public conscious of the good service being rendered.

Operation

Reliability of performance, accessibility of service points and facility of repair are expected as is efficiency of operation regardless of the type of pump.

Some of the problems of pump operation include packing troubles, bearing troubles, misalignment, cavitation, water hammer, power failure, noisy operation, suction line losses, discharge line losses, clogged impellers, improper priming, air leaks into pump and others.

Regardless of the type of pump or the use, a preventive maintenance program and schedule should be set up in conjunction with its operation.

Deep Well Pump Purchase and Maintenance*

By L. J. ALEXANDER

Design Engr., Southern Calif. Water Co., Los Angeles, Calif.

THE Southern California Water Co. has 107 turbine pumps in operation and purchases an average of 10 complete units each year. These pumps are located in 29 operating districts. Geographically, the districts are scatttered from the vicinity of Sacramento to the Imperial Valley. They operate under climatic conditions ranging from the hot, dry desert to the snow-clad San Bernardino mountains. The wells in which the pumps operate are located at elevations varying from sea level to more than 7,000 ft.; the motors driving them vary in size from 7½ to 150 hp., and the capacity range is from about 100 to more than 2,200 gpm. In direct lift of water from the well, the variation is from just a few feet to more than 500 ft. below the surface.

The wide range of pumping conditions provides opportunities to shift pumps from one location to another, thereby practically eliminating the factor of obsolescence. A pump can always be installed in a well or system where it will operate to best advantage. With specifications standardized, it is possible to make these transfers even though there is considerable variation in character and quality of the water being pumped.

Wells and Water Quality

Wells drilled in Southern California are of two types: the California cable tool and the rotary gravel envelope. The cable tool method was developed in the early days of well drilling in Southern California because of the character of the geological formations into which wells must be drilled. These are all unconsolidated formations of the Recent, Pleistocene and Pliocene geologic epochs. The unconsolidation is such that open-hole drilling is impossible; the well casing must follow the drill. After the well is drilled, the casing, which is then in place, is perforated opposite water-bearing formations.

Rotary gravel envelope wells have preperforated casings set in the drilled and well-mudded hole. Gravel is then placed between the casing and the wall of the drilled hole.

The Southern California Water Co. has wells of both types, with depths ranging from less than 200 ft. to more than 1,900 ft. The unconsolidated formations in which these wells are drilled are so unstable that, regardless of the type of well, it is often impossible to keep out fine sand or silt. Even after very careful development of the well, it is occasionally necessary to resort to the use of a column check valve in the construction of a pump. In doing this a column check valve is installed immediately above the pump bowls to prevent water from draining out of the pump, with a consequent reversal of the flow from the well into the formation.

Sand within the water passages of the pump literally blasts away metal of bowls, impellers, shaft, casing and tubing. Experience has shown that bronze withstands this sand cutting better than any other metal. Porcelain-enameled cast-iron impellers have been tried, as porcelain is harder than sand and, thus, might be expected to withstand the abraison; but sand cuts into the cast iron where the enamel has been machined off, and cavities develop between the porcelain and iron. It is only a matter of time until the porcelain spalls, due to corrosion of the iron.

Because many of these formations from which water is extracted were laid down under water, there are large areas where gases such as methane, carbon dioxide or hydrogen sulfide are entrained. These gases (or air from water falling from perforations above pumping water level) cause turbulence in the pump, and, in turn, excessive corrosion. Bronze and stainless steel withstand such corrosion better than iron or steel. In the pump column, at the top of the bowls, a short section of bronze tube will often withstand the corrosion caused by turbulence.

stainless steel shaft, bronze bowls and impellers in the bowl assembly, a 5-ft. section of bronze oil tube, a stainless steel line shaft from bowls to static water level, with a coating of coal-tar enamel outside the oil tube and inside and outside the eduction pipe.

To check corrosive waters, the Wintroath Pump Co. has demonstrated that the better the grade of metal, the more resistant it is to corrosion. Many pump manufacturers, for their standard sales product, use an ordinary run of foundry gray iron. The Wintroath analysis shows a rather high electric potential between ordinary gray iron, bronze and stainless steel, which seems to be additional proof of what practice has long demonstrated: that the

TABLE I
Analysis of Water

	City Creek	Foothill	Garvey	Wadsworth	Golden West	Avalon	Colden	Pacific
Sodium	104.4	37.7	19.6	378.6	32.2	49.5	57.3	63.7
Calcium	1.2	32.1	37.6	10.0	67.5	69.6	106.8	105.2
Magnesium	Trace	6.7	11.2	2.5	10.3	13.4	21.8	42.7
Sulfate (SO_4)	84.5	7.2	18.2	3.8	44.1	91.2	197.3	179.0
Chlorine	19.0	12.0	20.0	198.0	29.1	33.0	53.5	82.0
HCO_3	109.3	201.3	164.7	699.0	207.3	231.7	244.0	335.5
Total solids	319.0	321.8	284.5	1319.9	392.9	492.4	698.4	839.1
Carbonate hardness	3.0	107.5	135.0	35.0	170.0	195.0	200.0	275.0
Other hardness	....	....	5.0	....	16.5	34.0	156.5	162.0
Total hardness	3.0	107.5	140.0	35.0	186.5	229.0	356.5	437.0

The well waters pumped represent a wide range in chemical characteristics. Hardness varies from just a few to more than 500 ppm.; the pH is between about 7.3 and 8.0. Total solids vary from less than 100 ppm. to a maximum of 1,500 ppm. In several wells, free carbon dioxide appears and, in a large number, free hydrogen sulfide. Some waters have no trace of either iron or manganese; others have as high as 2 ppm. iron and 1 ppm. manganese. Table 1 shows this wide range of chemical character in the water produced. It has not been possible to relate corrosion rates directly to the acid radicals contained in natural waters.

The most troublesome conditions under which pumps operate exist in those wells in which the waters have been highly contaminated with the iron and sulfur group of slime-forming organisms, and contain as much as 2 ppm. iron and 1 ppm. manganese and have a high concentration of free hydrogen sulfide. Such waters are devoid of dissolved oxygen, but the slime-forming organisms are anaerobic. Slime coatings of considerable thickness will form even on highly polished rotating parts, such as the impellers. As the slime increases in thickness, the water passage space is reduced in area; and the efficiency of the unit reduced.. Occasionally graphitic corrosion takes place to an alarming degree where these slime-forming organisms are present. Bronze parts are the least affected by the slime formers.

Corrosion

Corrosion of turbine pumps results from several causes: chemically corrosive waters, entrained gases, bacteria and differences in electric potential between parts of the unit. How each factor operates or affects the other is not known, but it is obvious that corrosion does occur and that preventive measures are necessary.

In extreme corrosion, whatever the cause, the best preventive measures are to use a finer the metallurgy, the better the completed product.

Speed of rotation is another factor. It seems that the higher the speed, the greater the rate of corrosion. The author has found no satisfactory explanation of this correlation, and cannot determine whether it is due to corrosion alone, or partly to the turbulence caused by high velocity.

No attempt has been made to weigh individual parts of the pump to determine the extent of corrosion or wear in terms of the percentage of metal lost. Such an analysis in turbine pumps has little practical value because corrosion and wear never take place uniformly. A section of pump casing may lose less than 1 per cent by weight and still be unsafe because the casing is pitted. If pitting is allowed to continue, holes will cut through the casing and, under the high head of water in the pump column, act as nozzles. Wells have been damaged by such holes drilled through the well casing, and the loss of water through holes causes appreciable loss in pump efficiency. Corrosion and pitting at or near threads of the casing so weakens the pipe that failure can occur at a joint. When this occurs, the entire weight load of the pump and the hydrostatic thrust of water load are transmitted to the motor bearing and the rotating impellers. Such loads will wreck the entire unit.

In the pump bowls, a fraction of one per cent loss in weight, if in certain places, may be serious. On the other hand, if corrosion or sand cutting is uniform throughout, a 15 or 20 per cent loss in weight may not be serious.

Corrosion of the tubing may permit water under high head to enter the peripheral space between the tubing and the rotating pump shaft. Water will then shortly find its way out through the top of the tubing. When this occurs, the motor windings are often sprayed with water, resulting in a burned-out motor. Of less serious conse-

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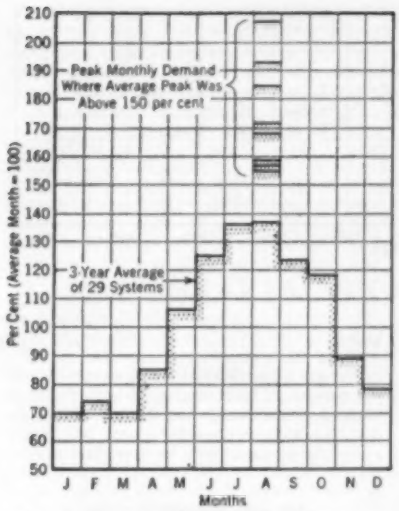

Peak Monthly Demand Where Average Peak Was Above 150 per cent
3-Year Average of 29 Systems
Per Cent (Average Month = 100)
Months
J F M A M J J A S O N D

Fig. 1. Average Monthly Production for All Systems

quence, but equally troublesome, is the resulting corrosion of the line shafting. The company's specifications do not permit a packing gland at the top of the tubing, because a packing gland prevents the appearance of oil and water at the pump head. When even a very small hole appears in the tubing it can be detected quickly and immediately repaired.

Very slight wear in the motor bearings, even a fraction of one per cent, may change the position of the impellers in the bowls, and cause them to wear excessively. The efficiency of the unit is lowered almost immediately, even before serious wear occurs. Excessive wear in motor bearings also causes misalignment of bearing housings. Oil is thrown out of the housing and, in a very short time, saturates the motor windings so thoroughly that nothing short of rewinding the motor will save it.

No mathematical relationship or formula can be developed or deduced to replace experience and visual inspection in the choice and extent of repairs and replacements to parts of the pump, when it is pulled for overhaul.

Variation in Demand

The variation of consumer demand in arid countries is great. All living things require water regularly, but in Southern California nature provides water only in the winter rainy season. Irrigation is therefore necessary. Domestic water service must provide for irrigation of lawns, shrubs and flower gardens, as well as for industrial and household consumption.

Fig. 1 shows the Southern California Water Co. monthly production compared to the average month (taken as 100 per cent). Together with the 3-year average for the 29 systems, the maximum months for several of the smaller systems are also shown. It appears that the smaller the system, the greater the peak demand. The average day of the maximum month averages nearly 140 per cent of the yearly average day; but the average day varies widely in the various systems. The average daily demand for 1945 is shown in Table II. This table also shows the relationship of the maximum day to the average day.

There is an even greater variation in hourly demand. Fig. 2 shows the average variation for each hour of the maximum day. The broken line represents the average of three consecutive maximum days in the Lennox system in 1942.

These curves all show the necessity for a large available capacity in primary pumping equipment. On the other hand, they show that, for large portions of the year, much of the equipment must remain idle. Experience has demonstrated that idle equipment deteriorates nearly as rapidly as operating equipment. The causes may be different, but replacements are just as costly. To overcome this problem partially, all equipment is operated at least once a week.

Weekly operation keeps the well in good order, dries out the motor windings, prevents "freezing" of bearings—particularly in the line shaft—tends to reduce the accumulation of slime growths and assures the operators that the equipment is in good order. This last is important because all equipment must "cut in" quickly and automatically in case of fire.

Planned Operation

Although all equipment is automatic, the time each unit operates can be predetermined. The general plan of operation to assure an adequate dependable primary supply is laid out in the engineering department. This plan is based on a study of the distribution pipe system and the location of the various pumping plants. Elevated storage is always considered as a balance against the maximum hour, and it is also desirable to consider it as a safety factor. Each plant is automatic, operation being controlled by pressures within the adjacent distribution system. Other factors entering into the setting of these controlling pressure ranges are: the quality of water produced at the plant, the efficiency of equipment, variations in demand, the needs of fire protection and the manpower available to operate the equipment.

The carrying out of these planned operations is under the direction of the construction engineer, who has charge of all field work on new construction, as well as maintenance, repair, replacement and operation. The district superintendents, of course, are "on the ground" and carry out most of the details of the operation of pumping plants.

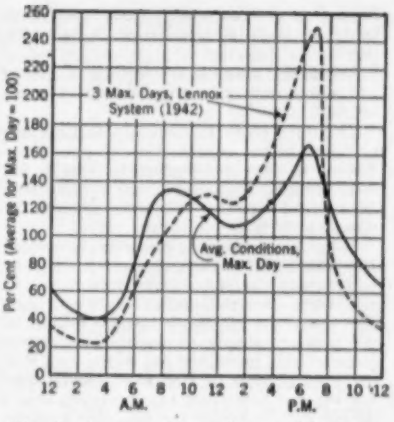


Fig. 2. Average Demand on a Maximum Day

Checks on Operation

To check the overall engineering plan, periodic pressure surveys are made. Complaints of poor water service are also checked against planned operation. The operation policy is to render an adequate and dependable water supply to all consumers at all times. During the war years, this has at times been difficult, but, with a little more time and the delivery of some needed materials, the policy will again be maintained.

All the factors involved in such operation make necessary continuous checks on equipment. In doing this, three principal checks are made regularly on all operating equipment.

The first check is made in the statistical branch of the engineering department. All field pumping records are assembled and checked in the office and the performance of each pumping plant is checked each month. A computation is made of the power in kilowatt hours consumed in pumping 100 cu. ft. of water (the company's unit of water measurement). This figure is balanced against the pumping water level in

TABLE II
System Demands

System	County	No. of Customers* 3/13/46	Gals. per Customer* 1945	Max. Day, Per Cent of Avg. Day, 1945
Artesia	Los Angeles	547	423	199
Barstow†	San Bernardino	876	822	191
Bear Valley	San Bernardino	655	202	386
Bloomington	San Bernardino	376	394	193
Calipatria‡	Imperial	290	1621	...
Niland	Imperial	125	...	...
Bell	Los Angeles	2,549	460	174
Florence-Graham	Los Angeles	5,986	695	135
Cardena	Los Angeles	4,048	432	230
Lawndale	Los Angeles	2,747	378	201
Lennox	Los Angeles	4,569	370	172
Normandie	Los Angeles	1,650	324	198
So. Los Angeles	Los Angeles	7,905	359	208
Claremont	Los Angeles	1,185	707	311
Cypress	Orange	126	286	243
Highland	San Bernardino	603	388	158
Hollyda e	Los Angeles	1,451	404	203
Huntington Beach	Orange	1,549	694	267
Oak Park	Sacramento	1,104	497	293
Ojai	Ventura	591	478	166
Olive	Orange	176	335	278
Placentia§	Orange	623	311	...
Atwood	Orange	...	...	...
Sunland-Tujunga	Los Angeles	3,359	432	201
Venice-Culver City	Los Angeles	14,978	515	139
Walnut Grove§	Los Angeles	62	...	...
Wilmar	Los Angeles	3,062	325	190
Los Alamitos	Orange	215	527	172
Stanton	Orange	209	229	228

*An average of 4 consumers is served by each customer's service connection.
†Industrial use eliminated.
‡Unmetered supply; consumption determined from several tests.
§Part of supply unmetered.
‖New system averages not established.

the well to determine the power, in kilowatt hours, required to raise 100 cu. ft. of water 100 ft.

The second check is the reading of power and water meters by the field operator on his daily rounds.

The third check immediately follows any variation in the consumption of power per 100 cu. ft. of water produced. This is the field check by engineers of the construction department of the efficiency of all the pumping units at the plant.

Wear or corrosion is immediately evident from one or all of these checks. During the war, when materials were difficult to obtain these checks became very important; they were the insurance against failure of the primary supply of water. The importance of this insurance lies in the fact that the total number of customers served during the last five years has increased nearly 10 per cent, whereas the available capacity of turbine pump production has decreased slightly. The result is that on maximum days every piece of equipment is in operation to meet the maximum hour.

Maintenance Program

Both the construction department and the engineering department work in close co-ordination on all phases of the company's operations. Seventeen years of cooperation has built up mutual understanding of the problems of each department. The result has been the adoption of certain theories and policies regarding design, maintenance and repair and operation.

The turbine pump maintenance program attempts to keep equipment in the best operating condition possible. Experience has shown that this policy can be carried out by pulling pumps for overhaul every 2, 3, 4 or 5 years.

Two-year schedule. Where the pumps are operating in "bad water," containing iron and sulfur organisms, or iron and manganese accompanied by hydrogen sulfide, or in wells which produce large quantities of sand, with the pumps operating under heavy-duty conditions—that is, for long hours every day in the year—a 2-year overhaul interval is scheduled.

Three-year schedule. No pump in "bad water" is permitted to operate beyond a 3-year period regardless of the number of hours which it may have operated.. Normally, heavy-duty units are overhauled on a 3-year period, even in good quality waters.

Four-year schedule. Pumps operating under relatively light duty and under "fair" water quality conditions are overhauled every 4 years.

Five-year schedule. Regardless of the characteristics of the water or the conditions of pump operation, no pump is permitted to run more than 5 years without an overhaul.

Extent of Repair and Replacement

When pumps are pulled from the well they are completely disassembled in the field or in the pump company's shop. Each part is subject to inspection by a trained engineer.

Generally, the inspections reveal the need for the following repairs:

Bowls

The top and bottom bearings or bushings are replaced. The replacement of main bearing housings or castings, however, is seldom needed. New wear and seal rings

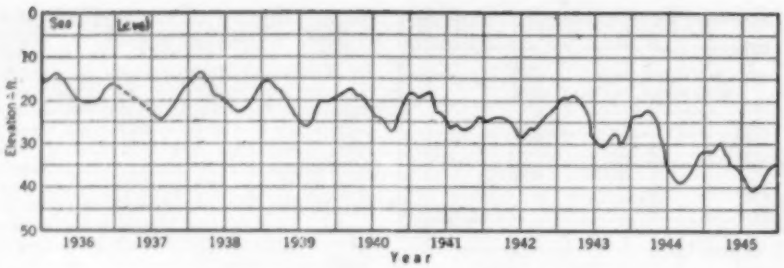


Fig. 3. Variations in Static Water Level of a Well

are nearly always installed, on both intermediate bowl castings and impellers. Intermediate bowl castings are replaced when not sufficient metal remains to permit machining for the installation of new rings or when excessive corrosion or sand cutting is apparent; and impellers are replaced for the same reasons. A new stainless steel pump shaft is installed only if injured in disassembly or when there is a change in basic bowl design.

Column

The most serious pump column replacement problem occurs with that portion of

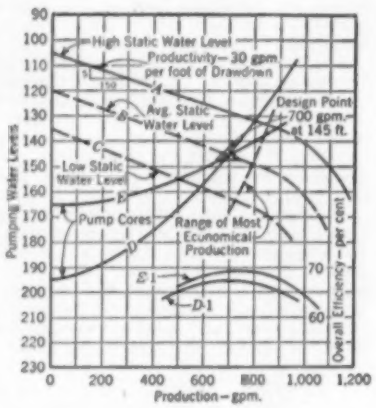


Fig. 4. Design Conditions for a Well

the column immediately above the pump bowls. This section is subject to more corrosion, sand cutting and wear of all sorts than any other, probably as a result of some turbulence in the water as it leaves the bowls. The first joint of casing above the bowls generally needs replacing or "pup jointing," that is the replacement of a portion of the casing with new pipe. Pup jointing is accomplished by cutting off the corroded section and using a pipe coupling to install a short piece of pipe that makes up the required length. The oil tubing often shows results of corrosion both inside and outside, between the static and pumping water levels. This occurs because water alternately will rise within the oil tube to the static water level of the well and drain out to the pumping water level during operation. The line shaft also becomes corroded within this range and must be turned end for end and reground at the bearing points on each overhaul. Often individual pieces of shaft can be shifted within the assembly to overcome wear or corrosion. The line shaft bearings or tubing couplings are all sized, and are replaced if they show wear of 0.012 in.

Motors

For each overhaul, motors are taken to the company's electric shop, where they are cleaned, reinsulated, and have their bearings checked, so that the motor goes back as nearly as possible in perfect condition.

Manufacturers' Service

Even under emergency conditions, working around the clock, it requires two or three days to pull, tear down, inspect, repair and reinstall a deep-well turbine pump. Failures of pumping equipment occurring on peak days or even peak months can be serious. It is the general practice in designing water supplies utilizing ground-water reservoirs to have primary capacity to meet at least the maximum day. Maximum hours can be taken care of by elevated storage.

During the war, it was nearly impossible to obtain sufficient materials to keep production facilities ahead of demand. It seems even more difficult now. The rate of population growth in Southern California is greater than ever before. It is, therefore, highly important to keep equipment in the best possible condition.

Emergencies, however, do occur. It is then necessary to move, and to move quickly. The company has always required that repairs be made by the manufacturer. Consequently, deep-well pumping equipment is purchased only from those manufacturers who are prepared to render immediate service. Only three manufacturers who can meet this specification have yet been found.

Choice of Pump

As is true in any arid country, Southern California has cycles of rainfall. These cycles recur from season to season and from year to year. The result is that the underground storage, as reflected in static water levels, varies both seasonally and by cycles of years. The season-to-season cycle indicates a range—often as much as 50 ft. —from a high in February and March to a low in September and October. The general conditions are illustrated in Fig. 3, which shows the variation in static water levels for a 10-year period on one company well.

Various water-bearing formations, whether Recent, Pleistocene or Pliocene, show different productivities. This productivity can be rated as the production volume in gallons per minute per foot of drawdown, and is the slope of Curve A, Fig. 4. The most economical production is always on the straight line portion of the curve, a short distance before the accelerated downward slope begins. No pump is ever chosen with a capacity greater than the most economical production of the well, as this factor seldom coincides with the

maximum efficiency of the pump. Figure 4 shows the design conditions of a recent well. The well was completed in the high static water level period and drawdown Curve A was obtained from test. Curves B, the average static water level and C, the low static water level, have been estimated from experience. Curves D and E are those submitted by two manufacturers for head capacity performance of a turbine. Curves D-1 and E-1 are the efficiency curves (ratio of power input at the meter to theoretical power required) and include all losses incurred in the motor, line shaft and bowls, and within the pump by water friction. Both performance curves were submitted by pump manufacturers to meet the design point.

It is interesting to note that turbine pumps are sold and purchased to meet one design point. This practice, promoted by the California Pump Assn., has been followed for years. The association has set certain standards of manufacture and fabrication and, for the sake of uniformity, a pump with a given head capacity and a given column length will be sold by all manufacturers at nearly the same price. Price, therefore, is not the controlling factor.

Even though its efficiency was less at the design point, pump D was chosen for the well because: (1) Pump E, at high water level, would operate below the range of most economical production; (2) the head capacity curve of D more nearly follows the range of the most economical production; and (3) Pump D produces more water when it is needed in summer low-water period.

A new condition has recently been imposed and influences the final choice of the bowl assembly. The Southern California Edison Co., which is now producing a 50-cycle alternating current, proposes to change to 60-cycles. This change will require the complete redesigning of bowls in a large number of turbine pumps, and to meet it, all pumps that will be purchased hereafter must be designed to operate on 60 cycles, but with enough additional stages in the pump bowls to operate temporarily on 50 cycles. This will provide for a minimum of changes in the pump and prepare for making the change with all possible speed.

The company purchases the complete unit installed in the well and ready to operate when electrical and pipe connections are made. The responsibility for individual parts of the units rests entirely with the one manufacturer, who is required to guarantee not only the pump but the motor he furnishes with it. The efficiency test following the purchase is for over-all efficiency of the complete unit.

Specifications

The standard specifications provide for the majority of operating conditions, although special conditions, already mentioned, at times require revision of the standards. Generally, the specifications are as follows:

Bowls

All bowl castings, including top and bottom bearing housings, shall be of the best grade iron used by the manufacturer. The impellers shall be of bronze containing 85-88 per cent copper, 5-10 per cent tin and 2-5 per cent zinc, and may have 5 per cent lead if the same bronze is used for both impellers and line-shaft bearings. They shall be machined so that no rough surfaces are in contact with the water. The pump shaft shall be of stainless steel. The suction shall be 10 ft. of standard pipe with a standard "Greene" strainer.

Pump Column Assembly

The line shaft shall be of cold-rolled steel with surfaces polished and shall be in 10-ft. lengths joined with couplings to permit butting of the shaft within the coupling. The oil tubing shall be in 5-ft. lengths joined with bronze guide bearings to provide a bearing at 5 ft. intervals on the line shaft. The eduction pipe shall be of standard weight pipe, joined in 10-ft. lengths. Spider guides shall be installed within the column at the points indicated on the well survey diagram.

Design Point

A performance curve of the proposed pump shall be submitted, indicating the performance of the pump from shut-off to its point of cavitation and showing the over-all efficiency curve. This efficiency curve shall show the guaranteed field performance of the pump as installed, and shall be computed by relating the power of input to the unit to the theoretical water horsepower.

Pump Head

The pump head shall be the heaviest casting constructed by the manufacturer to receive the motor required for the pump, have a discharge nipple of the same diameter as the pump column, and be at least 2 ft. long.

Motor

The motor shall be of such size that at no point on the performance curve will the rated horsepower of the motor be exceeded. The motor shall be a 440-v., 50-cycle, 3-phase, vertical, hollow-shaft motor. It shall be designed to receive an adequate thrust bearing.

Manufacturers' Specifications

The manufacturer shall submit complete manufacturing specifications which show the sizes of various parts of the column and the number of stages in the bowls. The speed of operation of the motor shall also be given, as well as the name of its maker.

The value of these specifications has been proved through extensive use. They standardize and simplify the problems of selection and maintenance of deep-well pumps.

DISCUSSION—T. E. LARSON

Chemist, Illinois State Water Survey, Urbana, Ill.

Corrosion experiences with deep well turbine pumps may or may not be considered serious, depending on the local physical conditions and the maintenance care provided. The economics of proper maintenance sometimes permits a $400 replacement at a 100-ft. setting biennially, with no regard to excessive corrosion rates, or may necessitate a $6,000 expenditure to pull a pump at a 600-ft. setting and replace column pipe, shaft and shaft tube.

Galvanic Action

The ordinary galvanic attack is aggravated if two galvanic cells are set up in series in the installation. Such a situation exists if bronze impellers are used with cast-iron bowls and copper-alloy bearing-retainers are used with a water-lubricated steel shaft. In oil-lubricated pumps, the galvanic series is created if bronze impellers are used with cast-iron bowls and water is permitted to enter the enclosure tube above the bowls and to come in contact with the bronze bearings and steel shaft. It is obvious in these situations that current will flow from the iron impeller seats through the water to the bronze impellers and up the shaft to the bearings. At this point the current will leave the shaft and flow through the water to the bearing retainers or to the bearings and down the column pipe or enclosure tube to the bowls. A vicious cycle of galvanic action can be set up in this manner.

Water-Line Corrosion

Water-line corrosion is usually due to the existence of an "oxygen concentration cell" near the water line on the outside of the column pipe, and is adequately described in many texts.

Carbon Dioxide Corrosion

Carbon dioxide corrosion takes place at the high-pressure points in the pump bowls and between the column pipe and shaft tube. It causes noticeable pitting in the bowls, on the column pipe and shaft tube just above the bowls, and, to a lesser extent, just above the spiders.

A possible explanation of this type of corrosion is that it is caused by the release of gas bubbles in the water at the low-pressure points on the underside of the impellers and possibly at the entrance to the suction pipe. This can happen, particularly if rough edges are present. The gas is composed of nitrogen, water vapor and carbon dioxide, and can be expected in any ground water under artesian pressure. When formed, the gas bubbles pass through the turbine and column pipe and undergo changes in volume due to the changes in pressure that take place. They are carried through the pump into the column pipe.

A rapid increase in pressure gives the carbon dioxide a higher solution potential and, as it dissolves, the water film on the surface of each bubble becomes excessively acid through the formation of carbonic acid. As the gas bubble with its acidic surface film passes over metal, corrosive action takes place.

Stray Currents

Stray currents are known to exist at many installations. To what extent they may damage the pump will depend on whether the polarity at any point enhances or inhibits corrosion.

Prevention of Corrosion

Prevention of corrosion depends largely on the type of installation, the corrosion expected or encountered and the economics involved. Consideration of the savings effected by preventive methods should include the power saved by maintained pump efficiency and the trouble and cost of pulling the pump, as well as the cost of actual replacements.

Operation and Maintenance of Centrifugal Pumps*

By R. B. RIDDLE

Utilities Superintendent and City Engineer, Frederick, Okla.

THE chief advantages of the centrifugal pump over other types of pumps are its simplicity, reliability, and ease of operation. Another important feature is that the discharge is smooth and continuous, and free from shocks and pulsations. Because the centrifugal pump is free from vibration, it does not require an elaborate foundation. Moreover, the centrifugal pump possesses the merits of high speed, occupies less space, is lighter in weight, and generally costs less than other types of pumps. The fact that the discharge from a centrifugal pump may be shut off by closing a valve in the discharge pipe without dangerous pressures being introduced or requiring the motor to be shut down is another great advantage.

Installation

In the installation of a centrifugal pump there are several important operations that must be given careful attention. These are as follows:

1. Set the base plate with the pump and the prime mover on a solid foundation, preferably of concrete, level carefully, grout the base plate in, and allow to set. See that the pump and the motor are in line, and that the shaft turns easily by hand after the anchor-bolt nuts have been tightened.

2. When the pump is set, connect the suction and discharge pipes; see that these pipes are self-supporting, in order to avoid strain on the pump and ensure proper alignment. Be sure the pump and the motor are dowel pinned to the base when they are in proper alignment.

3. Locate the pump as near the supply intake as possible. The maximum suction lift, including pipe friction, varies with the size of pump and the liquids to be handled. Hot water or heavy liquids must flow to the pump under a positive head, this head varying according to the difference in temperature of the liquid or the viscosity of the liquid.

4. Never use pipe sizes smaller than the pump calls for. For long pipelines, use pipe two or three sizes larger. Make the suction pipe as short as possible and avoid bends and elbows. Make sure that there are no air pockets in the line, and that the suction pipe is absolutely air tight.

5. Place a check valve and a gate valve in the discharge pipe as close as possible to the pump. The check valve must be placed betwee the gate valve and the pump in order to be able to inspect or repair the check valve.

6. Always provide a strainer on the end of the suction line. This protects the pump from being choked by foreign matter and ensures safe operation.

7. To pack stuffing boxes, do not draw the glands up tight, but allow a reasonable leakage, which lubricates the packing and prevents the shaft being corroded. Pipe the leakage from the tap in the bearing bracket to a sewer or drain.

8. Before starting the pump, clean the bearings with gasoline or kerosene and fill the oil reservoirs with highgrade lubricating oil, as high as the tap of the oil gage indicates.

Operation

In operating a centrifugal pump, certain basic rules must be remembered, as follows:

1. The pump must always be primed gefore starting, otherwise the interior parts, which depend upon the water for lubrication, will be injured. Never run a centrifugal pump empty.

2. As soon as the case is primed, the pump should be started with the dischage valve closed and brought up to speed.

3. Open the gate valve slowly until the desired quantity of water is obtained. Failure of the pressure to increase with the speed indicates air in the pump casing. In this case, stop the pump and prime again.

4. As long as the water and, consequently, the case does not heat up excessively, due to friction produced by the rotation of the impeller, the centrifugal pump may be operated with a closed discharge valve. In contrast with displacement pumps, no by-passes are required.

5. Always run the pump in the direction of the arrow cast on the case. Centrifugal pumps can be run only in one direction.

6. During the operation of the pump, stuffing boxes and bearings must be inspected occasionally. The centrifugal pump does not require any other attention except to remove foreign material caught on the impeller.

7. If the pump is to be idle for long periods, it should be taken apart, cleaned, and oiled. This prevents the parts from rusting together and preserves their condition.

8. the pump is exposed to freezing temperature, it should be drained immediately after stopping.

Operating Problems

The common problems that arise in centrifugal pump operation may be classified and identified according to the following:

1. If, after starting the pump, it throws a little water at the first few revolutions and then churns and fails to discharge more, it is evidence that the air is not all out of the pump and the pipes, the suction list is too great, there are pipe leaks, or the suction is long and the discharge head is insufficient.

2. If, when first started, the pump throws a full stream for a few minutes and then fails, it is caused by failure of the supply or recession of the water below the suction limit. The remedy for this latter condition is to lower the pump.

3. If the pump delivers a full stream of water at the level of the pump, but fails to pump to a higher discharge point, the speed of the pump is too low.

4. If the pump starts a full stream, and then the discharge decreases very slowly until the pump fails to deliver any water, it is caused by an air leak at the packing gland.

5. If the pump delivers a full quantity for a few hours and fails, the speed and water supply being unchanged, the suction pipe or the impeller is obstructed.

6. If, when running, there is a heavy vibration, the shaft has been sprung, the pump is out of alignment, or an obstruction has lodged in one side of the impeller.

7. If the bearings heat unduly, the bearings lack oil, there is an end thrust, or the belt is too tight.

* Reprinted from S. & I. W., Vol. 24, p. 327 (1952) by permission.

TEN PACKING "DONT'S" WORTH HEEDING

It is well known that "don'ts" are often more effective than "do's," so here are some suggestions and warnings arranged as "don'ts" that are based on many years of practical experience. They will be found useful in connection with the selection and installation of packings. To follow them may mean freedom from trouble that would occur when even the best obtainable packing is improperly installed.

1—DON'T fail to make clear what the packing is to pack. In other words, with what will the packing make contact?

2—DON'T guess at a size, diameter, width or height when ordering packings. Many failures have resulted from small errors in dimensions.

3—DON'T allow too little or too much clearance between follower plate and inside cup wall, or any metal parts behind any upright leather wall; 1/16 to 3/32 inch on each side, depending on size of packing, is usually recommended.

4—DON'T doctor packing lips with a pocket knife or file, or batter lip in installing. A rounded lip destroys the seal. Packings can be softened by soaking in warm water if necessary.

5—DON'T apply cup packings with flange too high for clearance at the head of the cylinder. Keep systems clean so sediment will not collect in cylinders and wear the packing.

6—DON'T apply cup packings to end of plunger which is badly worn; pressure will force the packing down into clearance between plunger and clyinder. Leather washers cut from old cup packings can be made to reline such equipment to proper dimensions.

7—DON'T apply "U" packings where plungers are worn without reinforcing under heel with leather cushion rings.

8—DON'T look for long service on scored plungers or in scored cylinders; resurface or reline such equipment to proper dimensions.

9—DON'T allow water to corrode cylinder walls, plungers or rods. Use an anti-rust agent that will prevent this and that will act as an effective lubricant.

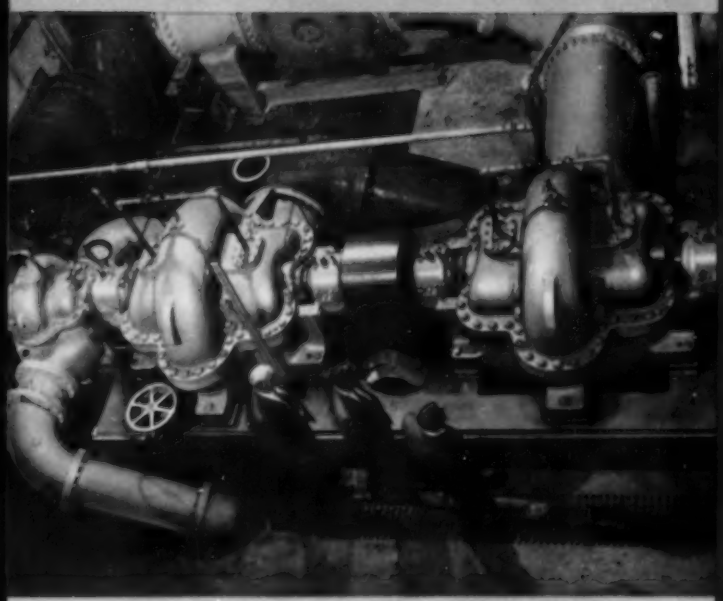
10—DON'T squeeze hemp or fabric filled "U" packings in glands where such packings are to replace solid section compression packings; set glands up to point where "U" packaings are free to function properly.

Contributed by *W. F. Schaphorst*, M. E., Newark, N.J.

ALLIS-CHALMERS

Builds

WORLD'S WIDEST RANGE OF PUBLIC WORKS EQUIPMENT



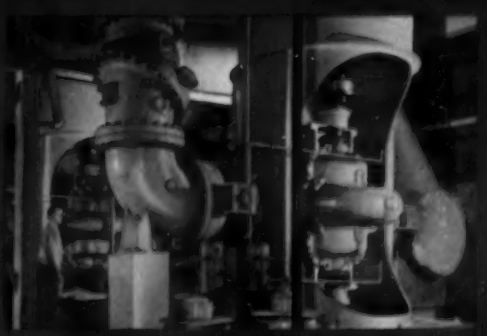
Milwaukee added 40 mgd to its pumping capacity by installing this 60-mgd Allis-Chalmers centrifugal unit in the space formerly occupied by one 20-mgd pumping engine. This new unit is driven by an Allis-Chalmers 3700-hp steam turbine and is also supplied with an A-C condenser.

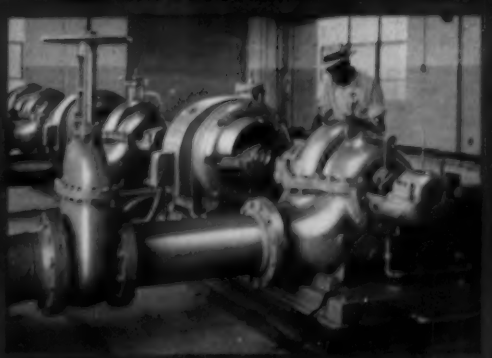
Allis-Chalmers can supply a major percentage of the equipment needed for sewage plants, water works, municipal power plants, street and highway construction, and other public works. See the three following pages for further information on A-C equipment.

The record of Allis-Chalmers in building centrifugal pumps speaks for itself. Of thousands built, no A-C centrifugal pump has ever failed to meet its guaranteed efficiency. This means that when you specify Allis-Chalmers you are getting exactly what you intended to buy . . . exactly what you need.

Hundreds of cities . . . large and small . . . are already profiting from the efficiencies of Allis-Chalmers pumps. The range of types and capacities of A-C pumps will meet the needs of any city. There are special pumps for water supply, fire protection, sewage, and drainage. Sizes range from small compact units handling only a few gallons per minute to huge 72-inch pumps capable of handling 300,000 gpm.

Also worth while remembering is that you can get the entire pumping unit from Allis-Chalmers . . . for this company builds motors of every type, for operating every size of pump. You can also get the proper A-C starter for controlling the motor.





25C6607C

How to make

SEWAGE DISPOSAL PAY!

Three Allis-Chalmers 120,000-cfm turbo-blower units installed in plant of Sanitary District of Chicago.

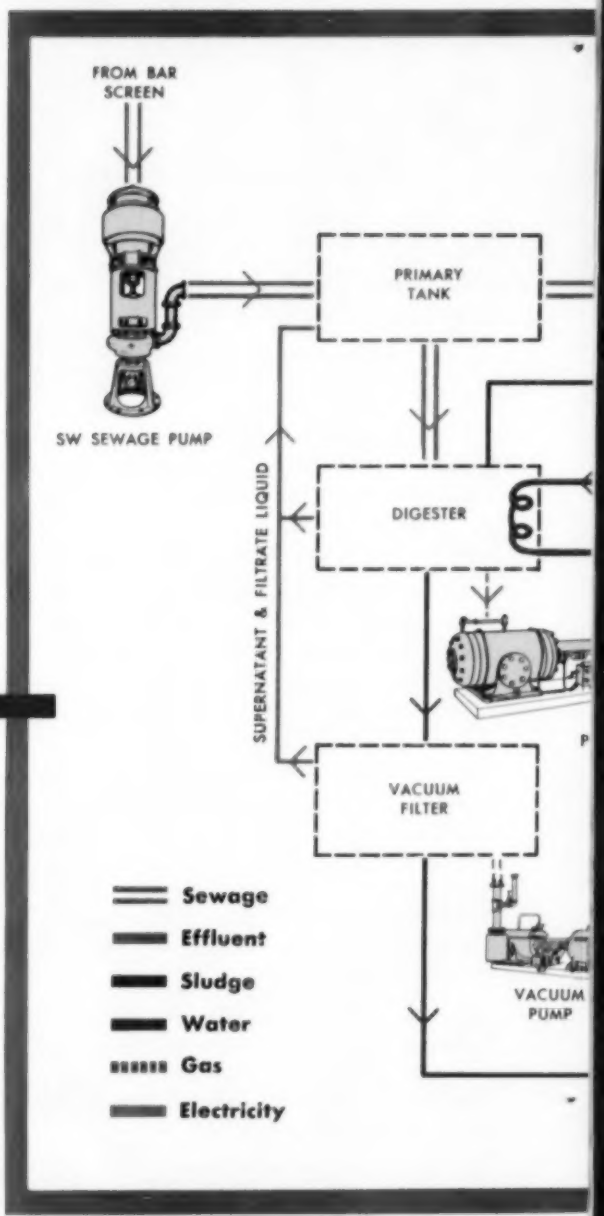
By-products can help pay part of sewage system expansion costs. Here's how...

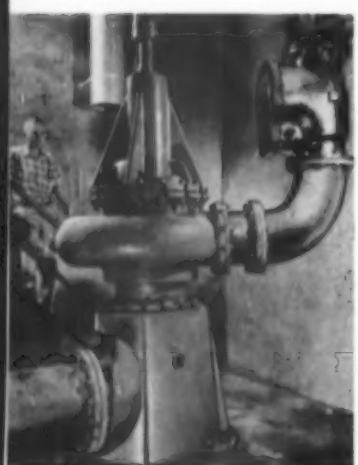
The flow sheet at the right shows two modern treatment methods that use by-products to help meet expansion costs.

- Some cities, through the sale of fertilizer, are recovering a large percentage of the cost of operation.
- Other cities are using digester gas to supply most of the sewage power and light needs.
- Many industrial sewage plants are paying their way with similar improvements.
- The increasing use of home garbage disposal units is aiding many municipal plants to increase their by-product value.

Get Help on Your Problem

Allis-Chalmers, builders of the world's widest range of public works equipment, can help you analyze your problem and select the proper equipment for your particular needs. For complete information on any of the Allis-Chalmers items shown here . . . call your nearby Allis-Chalmers District Office or write Allis-Chalmers, Milwaukee 1, Wisconsin.





Allis-Chalmers 16 by 14-in. vertical sewage pump on combined storm and sanitary sewer main.

Some A-C Products for Sewage Works

CENTRIFUGAL PUMPS—Vertical or horizontal, for sewage and activated sludge.

BLOWERS—For sewage aeration.

ROTARY VACUUM PUMPS—For use with vacuum filters in dewatering sludge.

ROTARY COMPRESSORS—For compressing digester gas.

DRYERS—For sludge dewatering.

VIBRATING SCREENS — For removing solids from liquids; also in fertilizer manufacture.

SIFTERS—For grading fertilizer.

ROLLER MILLS—For grinding fertilizer.

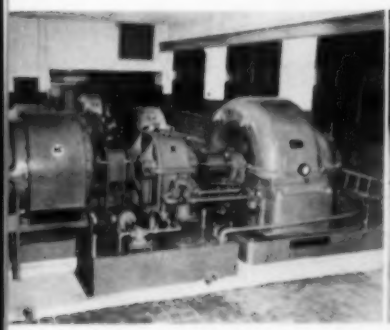
V-BELT DRIVES—Constant and adjustable speed.

MOTORS AND CONTROL—For all drives over 1 hp.

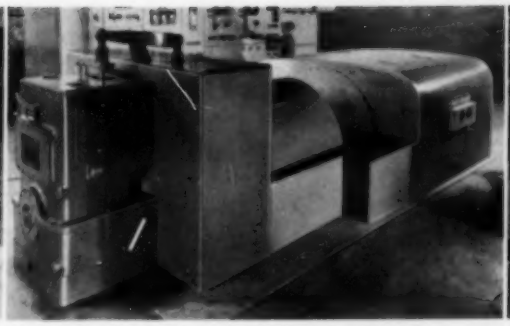
POWER EQUIPMENT—Steam turbines, condensers, pumps, water conditioning.

ELECTRICAL EQUIPMENT—Transformers, switchgear, circuit breakers, unit substations, generators, voltage regulators.

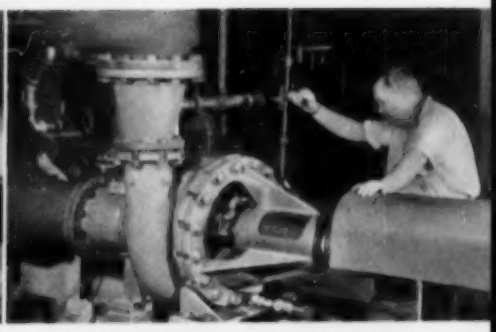
For complete information on any of the above items just mail the attached post card . . . or call your nearest Allis-Chalmers sales office. See list on page 4.



hree A-C blower units, 27,000 cfm, 0,000 cfm, 15,000 cfm.



A-C 2500-kw, 3600-rpm WA-Series steam turbine-generator unit with A-C switchgear in background.



A-C sewage pumps have wide impeller openings, rounded impeller inlets to pass solids freely.

Yes

I saw your ad in Water & Sewage Works Catalog and would like more information on the equipment indicated below:

- ☐ Water works pumping units
- ☐ Sewage pumps and drives
- ☐ Centrifugal blowers
- ☐ Vibrating screens; ☐ Sifters
- ☐ Roller mills; ☐ Rotary dryers
- ☐ Rotary compressors; ☐ Vacuum pumps
- ☐ Switchgear; ☐ Transformers
- ☐ Power generation equipment

shown in gray
is-Chalmers.

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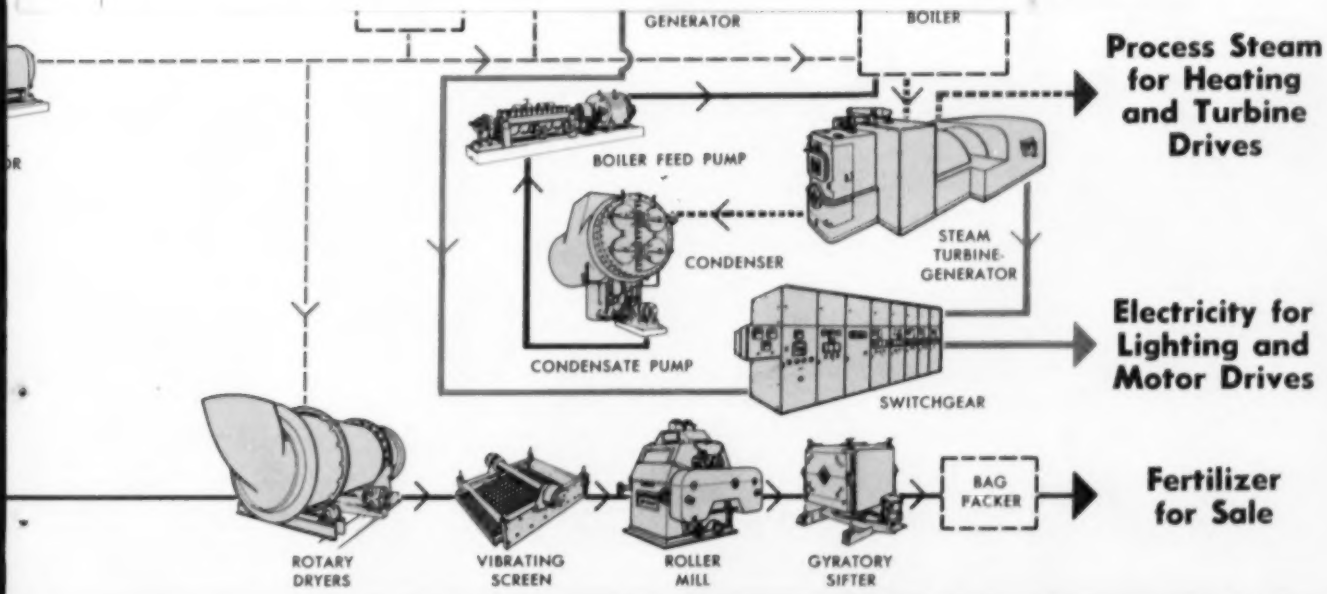

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Right: Rear view of 3000-kva, 4160-2400-volt unit substation with both incoming line section and distribution feeder section consisting of metal-clad switchgear.

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Deep Well Pump Testing*

by FRANK C. MIRAMONTES

Pump Testing Supervisor, Pacific Gas & Elec. Co., San Francisco

THE general theory and use of hydraulic and electrical instruments to test pumping plants have been the subject of many fine articles. The matter is also amply covered in textbooks and in some very excellent bulletins prepared by pump and instrument manufacturers. Hence, this article will be confined to the specific field equipment, methods and practices employed by the Pacific Gas and Electric Co., in testing the pumps of its customers in northern and central California. For the same reasons, formulas will be held to the minimum. Wells, as a separate subject, will be only partly covered.

The pump test service was started in 1923 by what was then the San Joaquin Light and Power Co., now a major division of Pacific Gas and Electric. At present nine two-man crews, strategically located from Bakersfield to Marysville, Calif., are equipped with hydraulic and electrical instruments to conduct field tests, all of which are made at the customer's request in the form of a signed application. A total of more than 70,000 tests have been made to date. Each test involves field measurements and notes, a typewritten report to the customer (with any recommendations needed), and personal delivery or a letter of transmittal. The letter usually contains power usage figures, data on the total amount of water pumped and unit cost figures. As the work is seasonal, during the summer farm irrigation season the crews are usually one or two months behind the test applications. The company conducts free tests because a customer with inefficient pumping equipment will frequently believe that the poor performance of the pump and his increasing power costs are due to improper electric service or excessive rates.

Essentially, the tests yield reasonably accurate, usable information about the pumping plant, which the customer can employ to maintain minimum pumping costs, maximum flow or both. Unless the customer represents a large organization rather than an individual water works operator or farmer, he can usually not obtain this service elsewhere except at considerable cost, if at all. More than 6,000 tests are made each year, and in 1948 approximately 5.2 per cent involved water works pumps. It is the desire of the company to be of maximum service to all classes of customers—agricultural, industrial or water works. As all but a very few of the company's 50,000 agricultural customers have no engineering service available, however, the farmer receives about 87 per cent of the tests made annually.

Testing Procedure

The testing of a deep well turbine in its well requires not only proper instruments but a tester with sufficient knowledge of the characteristics and limitations of these instruments to obtain maximum accuracy when employing them, together with sufficient knowledge of pumps, motors and wells to interpret the data obtained. In order to be of service to the pump owner, the tester does not require instruments of laboratory accuracy. The time and expense involved in installing an orifice, nozzle or weir would seldom be justified, and, unless a great many conditions of the individual installation were taken into account, these instruments would be no more accurate than the pitot type. Fig. 1 shows schematically the test values for a deep well turbine delivering water to an elevated tank in a water system. Most of the terms are self-explanatory. Although the water-bearing stratum (there are often several) above the standing level may provide insufficient water to affect the well water levels materially, the falling water it produces frequently interferes with water level measurements. When the standing water level has been measured, the pump is started. In some areas the pumping level will stabilize in a few minutes, while in others it takes hours. Readings made while the water level is dropping rapidly are generally not simultaneous and also the test is not sufficiently typical of operating conditions to be of much use. When the level has stabilized, further test readings are taken. Assuming the speed to be relatively constant, figures for total lift (pumping level and discharge level), capacity (gallons per minute) and horsepower input to motor are required to determine the overall plant efficiency.

Where the distance to water is very small, the water level can often be seen and measured with a tape line. Usually, however, a sounnder tip is connected through a reel of flexible insulated wire to a voltmeter (or milliammeter) and a battery, the latter being grounded to the pump or well casing. The battery voltage is 4.5-45 v. When the sounder tip is lowered until its copper wire touches the water surface, completion of the circuit produces an indication on the voltmeter. The wire is then marked at the reference, usually the centerline of the pump head discharge, and the wire is then raised and measured with a steel or fabric tape. If the tip is lost, a new one is readily connected by a hand splice and taping.

Use of Air Line

Sometimes water falling from an upper perforation gives an unsteady indication on the meter, and the exact point of touching the pumping level cannot be determined. In this situation an air line can be employed. Also there may be so much oil on the surface that the electric circuit cannot be completed. More than 16 ft. of oil (bearing leakage) has been found above the water in wells, although that figure is above average

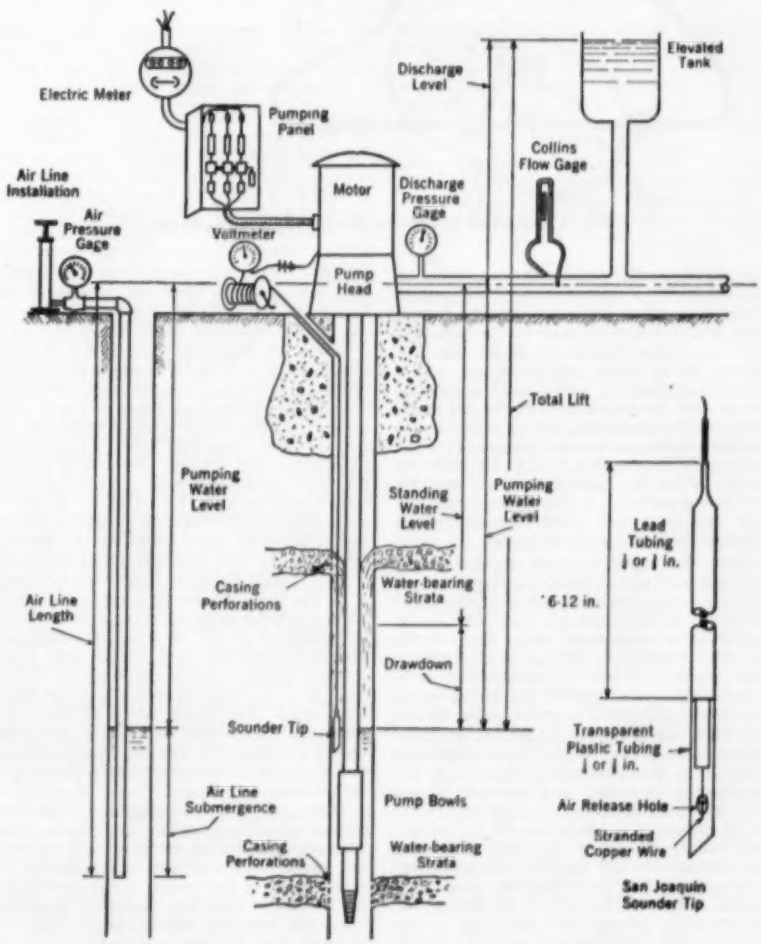

Fig. 1. TEST values for deep well turbine

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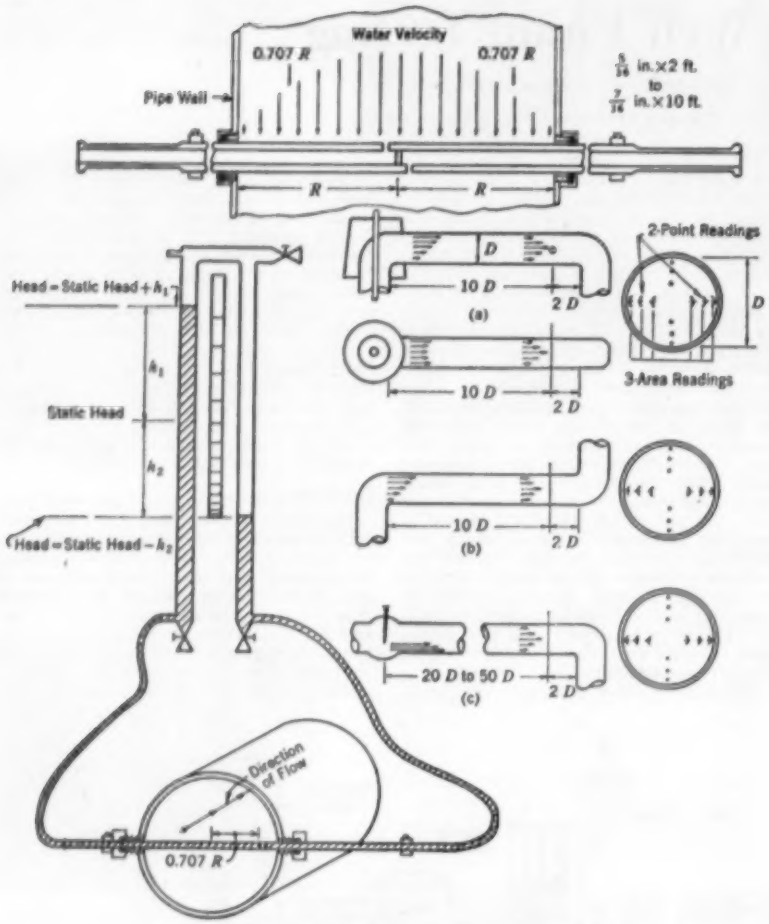


Fig. 2. COLLINS FLOW GAGE with water manometer

The lower specific gravity of the column of oil permits it to float on top of the water, giving it an upper surface somewhat higher than, and a lower surface far below, that which would be reached by water alone. A reading taken at the top of the oil would therefore indicate a water level somewhat higher, and at the bottom of the oil much lower, than true hydrostatic pressure would produce. Again an air line can be employed to provide true water levels. Its effective length minus the maximum gage reading (converted to feet) is the water level. Air lines are extremely reliable, provided the effective vertical length is known.

Often the standing water level, but not the pumping water level, can be obtained with an electric sounder. When a permanent air line is in place and a satisfactory standing level measurement with the electric sounder is possible, adding the maximum gage reading in feet to the standing level measurement will provide the effective air line length. Checking is necessitated by the possibility of breakage or leaks. If other means have failed, testers have sometimes lowered an electric-sounder line—with the sounder tip removed and an open sleeve over the bare wire end—down the inside of the column (which is free of oil) to obtain the standing level and thus determine the effective air line length. Unless handled with great care, for relatively short distances, there is danger of wrapping the sounder line around the tube line or entangling it in a "spider," when such tube line supports are used. A portable air line of rubber hose can be used in the normal well casing space when no permanent air line is available. As the length used can, of course, be measured while out of the well, it is only necessary to raise it 2-3 ft. after a measurement in the well to see if the gage drops an equivalent amount, thus indicating that the line is suspended free and not coiled up at an obstruction. For some hoses, stretch may become important when over 100 ft. of light air line is used. One line of single-ply hose (used to reduce diameter) was found to have a stretch of 19 ft. at 350-ft. suspension. Correction tables which proved fairly accurate were prepared for various lengths suspended and amounts submerged.

The capacity cannot usually be measured with the same degree of accuracy as other values, but the water level sometimes cannot be obtained at all because of insufficient clearance between well casing and pump column, flanged column couplings, a crooked well, mud or debris lodged above the water level, water level below bowls of nearly the same diameter as the well casing, or baffles installed around the column. The drawdown is a measure of the performance of the well rather than the pump.

Discharge head, measured by the discharge gage, is generally used rather than discharge level (the vertical distance from the pump head discharge centerline to the water level of the tank), which credits the pump with friction losses past the discharge gage and also the velocity head. Losses in suction pipe, column and head elbow are rarely credited, due to inaccessible gage connection locations when the pump is in a well. Accuracy on levels is limited only by the accuracy of the measuring tape and the pressure gages, the latter being periodically calibrated on a dead-weight tester.

Motor Input

Motor input is measured from the speed of rotation of the meter disc and from the constant applying to that particular meter, multiplied by the constants of the potential and current transformers, if used. Although rules require the electric meters to be accurate only within 2 per cent, the average error will be considerably less than 1 per cent. Motor (and pump) speed is measured with a chronometric speed indicator or revolution counter and stopwatch, either through a hole in the motor cover or with the cover removed. Centrifugal type tachometers are only satisfactory for continuous field use if handled very carefully and frequently calibrated. The voltage and current are measured at the switch box, generally using a split-core volt-ammeter. The voltage between phases is measured to determine if the motor is receiving proper potential, and the voltage to ground is checked to determine if any conductors are accidentally grounded. Current measurements show any possible current unbalance. A small current unbalance is relatively unimportant and may be due to voltage unbalance caused by a single-phase load on the same transformer bank which supplies the motor. Serious unbalance may mean damaged motor windings or an improper rewinding job and should be investigated further to forestall later burnouts, as well as to reduce energy losses. Calculation of horsepower or kilowatt input from voltage, split-core ammeter readings and estimation of the power factor is only relatively accurate and should be used merely for rough measurements or when the wattage cannot conveniently be directly measured.

Capacity Measurement

Capacity is measured with a pitot type instrument, either the Collins flow gage or the Hall tube described later. With a good piping arrangement, readings approach an accuracy of 3 per cent. Figure 2 shows, at the top, a sectional view of a Collins flow gage in a pipe. It can be moved to measure the velocity at any point across the diameter and during such movement has a constant area in the pipe so that it does not cause changes in velocity distribution. The Collins tube measures velocity by converting the water velocity (V), in feet per second, into head, in feet. One orifice faces upstream and produces a pressure equal to static pressure plus the head due to velocity (h_1). The other orifice faces downstream and produces a pressure equal to static pressure minus the head due to velocity (h_2). In the latter instance, all of the velocity is not converted, hence the constant k_2 used in the following formulas:

$$V = \sqrt{\frac{2g\left(h_1 + \frac{h_2}{k_2}\right)}{2}}$$

$$h_1 = \frac{V^2}{2g}, \qquad h_2 = \frac{V^2}{2g} k_2$$

In Fig. 2, D is the inside pipe diameter and R, the inside pipe radius.

Readings taken with the water manometer connected to this tube do not depend on measurements of static head, but the distance between water levels in the glasses is equal to nearly twice that due to the head produced by one orifice alone. The scale used to read velocity is therefore marked accordingly. The specific gravity of the water does not affect the velocity readings. Obtaining average velocity by multiplying centerline veloc-

ity by a constant is an extremely rough method, particularly with the lengths of pipe available at most pumping plants. It has been found that if fairly uniform velocity distribution exists (as shown), the average of velocities measured at two locations $0.707R$ from the center on either side of the pipe center will give results of reasonable accuracy. The tube is reversible, two readings are taken in each position and the average velocity is the average of four readings. This reversal will show up, by unbalance, any orifice stoppage or air pocket. The center velocity, although not used in the calculations, is also measured to give an idea of the shape of the velocity distribution curve and thus to decide whether a two-point, three-area or five-area traverse should be used. For greater accuracy, readings may be taken at three points on each side of center, as shown at Fig. 2 (a), right. These points are in three annular rings of equal area and the points are located, not at the midpoint of the ring, but so that each point separates the ring itself into two equal areas. For greater accuracy, five areas (five points on each side of center) may be used. If required, readings can also be taken at an axis normal to the above points (as indicated by the dots in Fig. 2, right). The axes need not be vertical or horizontal, but at the best angles to survey the velocity distribution of the pipe. For a three-area traverse, the reading points are at distances $0.204D$, $0.354D$ and $0.456D$, on either side of center. Five-area traverse readings are at $0.158D$, $0.274D$, $0.354D$, $0.418D$ and $0.474D$. Distances are given as functions of D because pipe tables and measurements generally list diameter instead of radius. With small pipes, care must be taken to keep the orifice out of the bushing or pipe wall.

The velocity scale is based on $V = \sqrt{2gh}$, but h represents nearly twice the h of an ordinary pitot tube (*see* Fig. 2). Capacity, in gallons per minute, equals $k_3\ 2.45\ D^2V$. The constant, k_3, is determined by calibration for various pipe sizes and includes the correction k_2 and the partial effect of the tube area in the particular pipe size manometers are used, and for velocities used. For lower velocities, 3- and 4-ft. above that of the latter, a vertical mercury manometer is employed. Pipe sizes below 3 in. are not desirable. Tubes are in 2-ft. and 3-ft. lengths in the 5/16-in. size and in lengths up to 10 ft. or more in larger sizes. Depending on the tube diameter used, ¼- or ⅜-in. I.P.S. ("Iron Pipe Size" standard) holes are tapped in the pipe.

Fig. 2(a) shows the plan and elevation of a typical pump head and discharge pipe, indicating the effect of the elbow and of the shaft tube on velocity distribution. It is obvious that readings taken in the discharge pipe right next to the pump head will have a greater than normal error, which would be true even if three or five points were used. At 10 diameters past the head and at least 2 diameters ahead of the next obstruction, a two-point or three-area traverse will generally be of ample accuracy. A typical example of unbalanced velocities produced by an elbow is illustrated in Fig. 2 (b). Figure 2 (c) shows why it is so difficult to obtain accurate flow readings past a partly closed valve, such as is sometimes used to limit pump capacity to a reduced well capacity. Although it is *theoretically* possible to obtain capacity accurately, even when a heavy unbalance of velocity exists, by taking a great number of readings on each diameter and by using a great number of diameters or axes, this method does not work in practice and a more suitable location had better be chosen. A two-point reading, using only a somewhat battered length of pipe temporarily connected to an outlet valve, will provide accuracy superior to a hundred traverse readings at a section with heavy unbalance. This statement is true of all types of pitot tubes, as well as of other instruments.

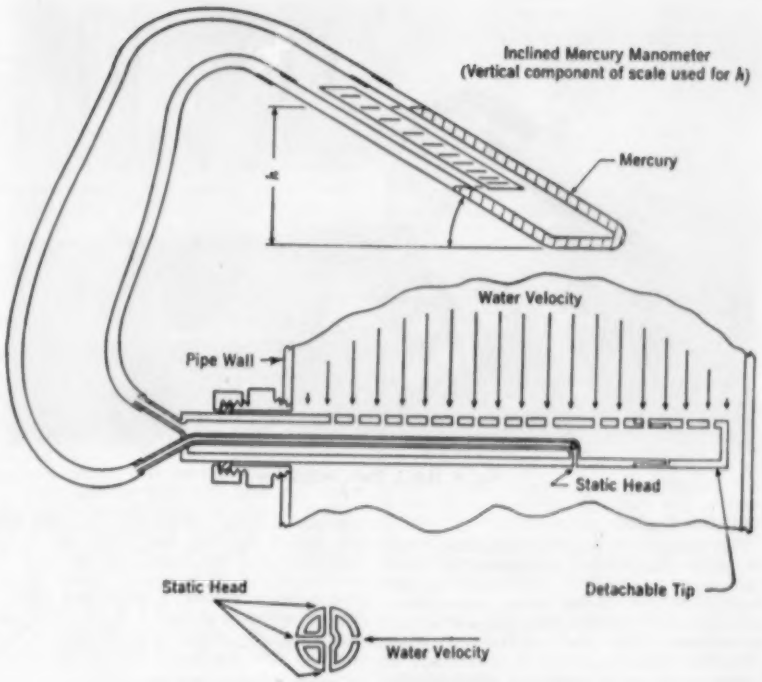


Fig. 3. HALL TUBE connected to mercury manometer

Approximately one-half of the 50,000 agricultural pumps, representing 1,000,000 hp. of connected load on the system, are served by the San Joaquin Power Div. of the company. In this area, the Hall type of pitot tube is used. While the two companies were still separate, San Joaquin adopted the single-reading tube instead of the Collins tube. Actually both instruments in proper hands produce very satisfactory results. Figure 3 shows a rough schematic cross section of a Hall type tube in a pipe and connected to an inclined mercury manometer. The tube shown has detachable tips covering pipe sizes 6-12 in. and, when placed in proper position in the pipe, is not moved from side to side or reversed. Three holes transmit static pressure to one side of the manometer, while a number of holes facing the direction of flow average the heads produced by the velocities which vary from side to side of the pipe. The San Joaquin Power Div. employs a mercury manometer with this instrument, the manometer being inclined, to increase the differential reading. Several small spirit levels are attached to the manometer itself. Each one, when in turn leveled by adjusting screws in the base, provides a separate convenient multiplying factor for the mercury differential on the incline to obtain the vertical component. A water manometer can, of course, also be used with this tube. Velocity equals $k\sqrt{2gh}$, k referring to the individual calibration of the specific Hall tube used. In practice, a scale proportional to $\sqrt{h}$ is used,, and this reading is multiplied by the pipe area, in square inches. Correction for the individual tube and the particular pipe size and capacity is then made by adding or subtracting a value of "gpm." determined by calibration. One ¼-in. I.P.S. hole is required. For both the Hall and Collins instruments it is important that the pipe at the point of velocity measurement be full, carry as little air as possible and be free of mud or other area-reducing deposits or objects.

Figure 4 shows a Hall tube connected to an inclined mercury manometer. Note the shutoff cocks to prevent loss of mercury while connecting up, and the three valves to remove air from the tube. One valve is near each hose bib and one is on the main body of the tube. Also note the adjustable clamp to position the tube. These parts were omitted form Fig. 3 for simplicity and clarity. The adjustable tips are shown at upper right.

A more-or-less standard type of pitot tube and water manometer used by the San Joaquin Power Div. for pipes over 12 in. in diameter, is shown in Fig. 5. With it, readings can be taken at three, five or more points on either side of center. In other divisions, various lengths of standard Collins tubes are used for this purpose. A standard type of pitot tube is also supplied by Collins for the use of the other crews where it is not convenient to pass the standard Collins tube through both sides of the pipe. As few water works installations in this territory use pipes greater than 12 in. in diameter, these long tubes are employed mostly for reclamation and irrigation projects pumping large volumes of water through relatively small lifts. In this field, pipe sizes of 4 ft. and capacities of 40,000gpm. are encountered. Current meters have measured capacities of approximately 1,000,000 gpm., representing the discharge of ten low-lift pumps. Separate pump capacities were determined. Measurements of kilowatts, volts and amperes were made for each 2,300-v. motor (225-550 hp.) and water elevation gages were checked with a surveyor's level. The company has a hydraulic laboratory at Fresno—designed, built and operated by the San Joaquin Power Div. —where field instruments can be tested against orifices, a weir and volumetric measurement. A motor-driven pump discharges water through selected pipe sizes. E. J. Griffith, Power Engr. of the Fresno office, has given considerable time to the design, construction and operation of this laboratory.

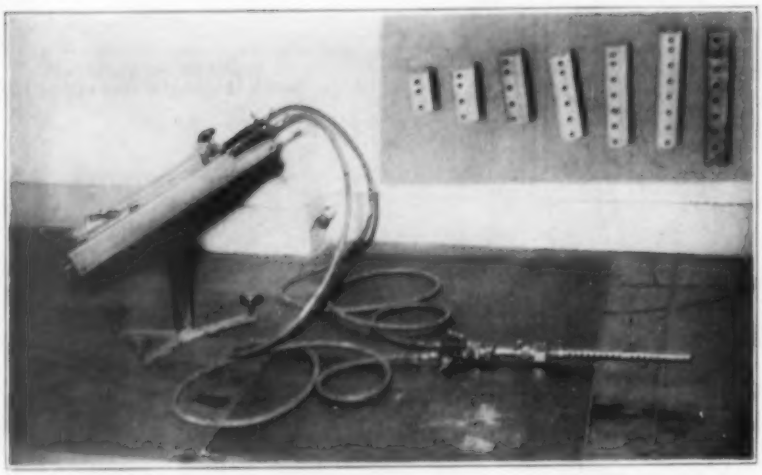


Fig. 4. HALL Tube Assembly

Pump Test Reports

The pump test reports emphasize total lift, water pumped and horsepower or kilowatt input to motor to determine overall plant efficiency. These items, with pump speed, are the elements of pump and motor performance. The yield of the well, expressed as "gpm." per foot of drawdown, is a measure of well performance which allows comparison with other wells in the same area or with the same well at other capacities.

Water temperature, in areas where sufficient history is available, gives some indication of which strata supply most of the water. A change in the temperature of a certain well between tests may indicate a loss of supply from one stratum due to well collapse. The use of this information requires considerable knowledge of the specific area. Water temperatures in the company's area of operation vary from 60° to 100°F.

A combined index of pump, motor and well performance is given by kilowatt-hours per 1,000 gal. of water pumped. This ratio is valuable in comparing pumping units on the same system and in estimating power usage for new plants.

When overhauling or new equipment is needed, the customer is urged to consult his pump dealer and well expert for final information, as it is not the function of the pump tester to recommend the particular type, size or manufacture of equipment to be installed or the specific type of overhaul to be performed.

Special Problems

As motor and pump manufacturers have in general done an excellent job of providing information on the routine care and maintenance of motors and pumps, and as some of the larger water works organizations have engineers and maintenance men of great experience, only a few brief notes referring to special problems will be discussed.

1. The better the piping arrangement used for testing, the more accurate will be the test results.

2. The ease with which the pitot type of tube can be installed, the water level obtained and horsepower input measured will determine how much testing a crew can do for a customer in one day's time. Under difficult conditions, only two tests may be made per day, while otherwise four to six tests are possible. Figure 8 shows two methods of discharge pipe layout which provide maximum accuracy and minimum test time to measure capacity. Holes for the pitot tube are drilled by the test crew about ten diameters past the pump, leaving two diameters ahead of the next fitting. If the pipe is below ground, a permanent pit, extending across it at least 3 ft. on either side (more for pipe above 12-in. diameter), to a depth of 6 in. below the pipe bottom and 3 ft. wide, will allow rapid instrument installation. Where adequate room exists, a head of perhaps 10 or 20 ft. due to water remaining in such a pipe is not prohibitive to installation.

Fig. 5. PITOT tube assembly

3. Mueller type cocks permanently installed in the pipe render it unnecessary to shut down the pump for tube installation. Such cocks, however, are not particularly desirable for measurements in small pipes as they generally will project into the pipe, causing disturbed flow. In larger pipes, great care should be taken in tapping and in installing the cock, to prevent excessive protrusion into the pipe. Also, where two cocks are used for a Collins flow gage, they must be in alignment.

4. A water meter is of great benefit. It allows a check of capacity at times of the year when the water table may be at an extremely low level and the pump test crew is not immediately available. If several pumps deliver water to a master meter, the addition of individual meters will indicate the failure of one pump. The meter should be installed approximately where the check valve is installed in Fig. 6 (a) or the gate valve in Fig. 6 (b), and these two items should be moved two to five diameters farther away from the pump. Meters without calibration for long periods lose their accuracy, however. Often checks can be made simultaneously using primary measurement with an accurately measured reservoir, the Collins flow gage or Hall tube and a water meter.

5. A means of access to the well casing should be provided either in the pump head base or directly under it, or, better yet, by means of a capped pipe, as in Fig. 6 (b). The pipe should be welded to the well casing or otherwise securely fastened and sharp edges smoothed. Public health agencies prefer a capped pipe to an open hole in the pump base.

6. Where previous difficulty has been encountered in obtaining the water level, because of insufficient clearance, falling water or excessive oil on the water surface, a permanent air line should be installed and its effective length plainly marked in the pumphouse. Water conditions will dictate whether steel or copper is used. With copper, if compression joints are used, they should also be soldered; otherwise vibration may produce leaks, rendering the air line useless. The customer may desire to have a direct-reading gage and hand pump permanently connected for his own readings, but the test crew will use their own calibrated gage. The air line should be securely fastened so that the attachment of a gage will not cause the line to drop down the well, and it should be sufficiently clear of the pump head to allow turning the gage for connection. If water level and discharge pressure records are kept during the summer low period, the same total-head condition can be duplicated in the winter—when more time is usually available for testing—provided that the discharge pressure can be raised by the use of a valve, or lowered by the use of a large drain valve, as required.

7. Information on the diameter and depth of each size of well casing (if more than one is used), the pump setting, bowl length, length of suction pipe and existence or absence of a strainer should be available in the pumphouse for the benefit of the tester in obtaining water levels and properly interpreting them. A well log, with the location of casing perforations, is of considerable use when reliably prepared.

8. Fuses should be of the proper size and should make good contact with the jaws. The overload relay mechanism should be inspected periodically for free movement which might be hindered by mud daubers and mechanical damage. Thermal relay heaters should be installed only in the size proper for the motor rating and the air temperature where the motor is located. Motors under average temperature and air circulation conditions can generally be safely over-

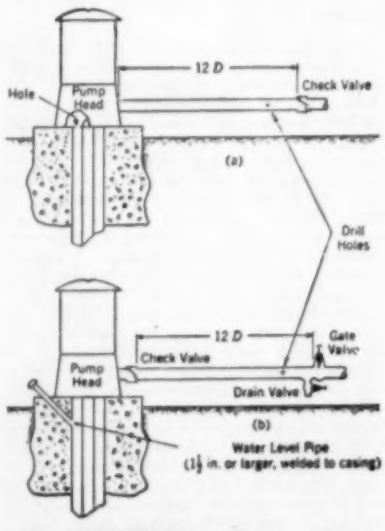


Fig. 6. PREFERRED installation methods.

loaded 15 per cent, but when in pits or other confined places, even the full rated load may be too much for motor safety.

9. A situation exists with regard to motor protection which is not universally understood and which will, therefore, be very briefly covered here. Two heater elements in the starter will protect a three-phase motor against practically all fault or overload conditions of excessive current occurring on the motor, or secondary, side of the power transformers. Under certain conditions, applying to transformer connections used in many parts of the country, the loss of one primary conductor (due to accidental breakage) will produce a current from two to three times normal in one motor conductor and perhaps only slightly more than normal current in the other two conductors. If this heavy current occurs in the unprotected conductor, and, as often happens, the motor does not stall and the current in each of the other two conductors is not enough to trip the starter, the motor is not protected. If the motor has already been carrying full load, it will probably burn out in 20-60 minutes; otherwise, a somewhat longer duration of the primary outage might be required for a burnout. Each year a large number of motor burnouts are encountered by the company for this reason. It is not practical, from the standpoint of the best all-around service and lowest rates to the customer, for the company to attempt to provide protection against loss of a primary wire on the primary, high-voltage side. The loss of one water works motor could be very critical during the summer heavy-load period, not to mention the expense of rewinding the motor. A thermal relay should be provided in the unprotected conductor. Thermal type fuses in the switch box will perform the same function, but it would be ideal to use three thermal relays and three thermal fuses. Electrical dealers can recommend the proper sizes of each.

10. Often a customer installs a new pump or new set of bowls with guaranteed performance values and requests the company to make a test to determine if the guarantee has been met. The company is ready to do so, but the tester will not advise the customer to accept or reject the pump as a result of the test. Also, when comparing test and guaranteed values, instrument accuracy limits must be considered.

Summary

1. Pump testing assists the customer in obtaining maximum capacity at maximum efficiency with minimum energy usage and minimum motor size.

2. Both Collins flow gage and Hall tubes, in proper hands, give satisfactory accuracy.

3. Although ten diameters after and two diameters ahead of elbows or other flow disturbers are desirable, satisfactory results can be obtained with half and sometimes one-third of these distances when care in positioning the instrument is exercised.

4. When water works customers are installing new plants or revamping old ones, it is an excellent time to rearrange piping for ease of capacity measurement. When the pump is out of the well, it is a simple matter to provide an entrance to the casing (if not already there) to allow water levels to be obtained.

5. A water meter properly located and periodically calibrated is of great assistance in taking measurements of capacity during the year and shows up decreased capacity due to wear or lowering of the water table.

6. Where exeprience shows that water levels cannot be easily obtained by the electric sounder, a permanent air line, properly measured and secured, should be supplied.

7. Information on well casing sizes and depths, pump dimensions in the well and effective air line lengths should be available near the pump.

8. All three-phase motors driving such important equipment as water works pumps should have three-element protection.

9. The Pacific Gas and Electric Co. is not always able, with existing test personnel and equipment, to test all plants as requested, particularly during the summer irrigation season. Most farms cannot provide a place to receive pumped water during the winter without damage resulting, while most water works can easily find space in their storage to allow pumping during the winter for an hour or so. Hence, it is preferable to test water works pumps during the winter, acceptance tests being an exception. Some larger water utilities may prefer to do part of their own testing.

10. Pump testing has resulted in higher average overall plant efficiency and has reduced power costs. Analysis of tests made for the company's farm, water works and other customers, and comparisons of their power accounts, show that thousands of dollars are saved each year as a result of the pump testing service.

Calculation of Pipe Lengths For Inclined Diagonal Runs

CHARLES FRICK

Water works men may find the following formulas interesting and helpful in figuring lengths of pipe and tie rods on inclined diagonal runs.

The formulas are also useful in finding the approximate angle of fitting, theta (θ), required (when bell and spigot pipe and fittings are used) when the dimensions in three planes have been decided upon.

The evolution of the formulas (see illustration) are also given in case the principle of revolution to a vertical plane may have further advantages in similar problems.

The subtraction of the center to end of spigot and center to back of bell taken from D gives the true length of pipe required.

Sketch Explanatory of Formulas for Lengths of Pipe for Diagonal Runs and Angle of Fittings

A.—When measurements in three planes are known, then

$$D = \sqrt{A^2 + B^2 + C^2} \qquad \text{Formula I}$$

$$L\ (\theta)^{-100} = \frac{\sqrt{A^2 + B^2}}{C} \qquad \text{Formula II}$$

Example: Let A = 5′6″, B = 3′0″, C = 14′9″
Find (θ) and length of pipe required on 8″ line.

$$D = \sqrt{(5.5)^2 + (3)^2 + (14.75)^2}$$
$$= \sqrt{30.25 + 9 + 217.56} = 16.025' \text{ say } 16'0''$$

$$L\ (\theta)^{-100} = \frac{\sqrt{(5.5)^2 + (3)^2}}{14.75} = \frac{\sqrt{30.25 + 9}}{14.75}$$
$$= \frac{\sqrt{39.25}}{14.75} = \frac{6.265}{14.75} = 0.42474$$

L (θ) = 23° + and a one-sixteenth curve may be used.
Length of pipe = D — (C to E of S. + C to B of B.)
= 16′0″ — (2′1″+) = 13′11″—

B.—When measurements in two planes are known and angle f fitting (θ) decided upon, then

$$D = \sqrt{A^2 + B^2} \times \text{Csc } (\theta) \qquad \text{Formula III}$$

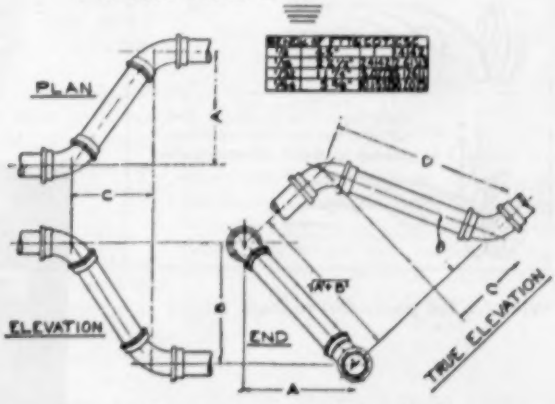
$$C = \sqrt{A^2 + B^2} \times \text{Cot } (\theta) \qquad \text{Formula IV}$$

Example: Let A = 8′0″, B = 9′6″, (θ) = 45°
Find—C and length of pipe required on 12″ line.

$$D = \sqrt{(8)^2 + (9.5)^2} \times \text{Csc } 45°$$
$$= \sqrt{64 + 90.25} \times 1.4142$$
$$= 17.56' = 17'6\tfrac{1}{4}''$$

Length of pipe = D — (C to E of S. + C to B of B.)
= 17′6¼″ — (2′1⅞″) = 15′4⅜″

$$C = \sqrt{(8)^2 + (9.5)^2} \times \text{Cot } 45°$$
$$= \sqrt{64 = 90.25} \times 1$$
$$= 12.42 \times 1 = 12.42' = 12'5''$$



Sketch explanatory of formulas for lengths of pipe for diagonal runs and angle of fittings

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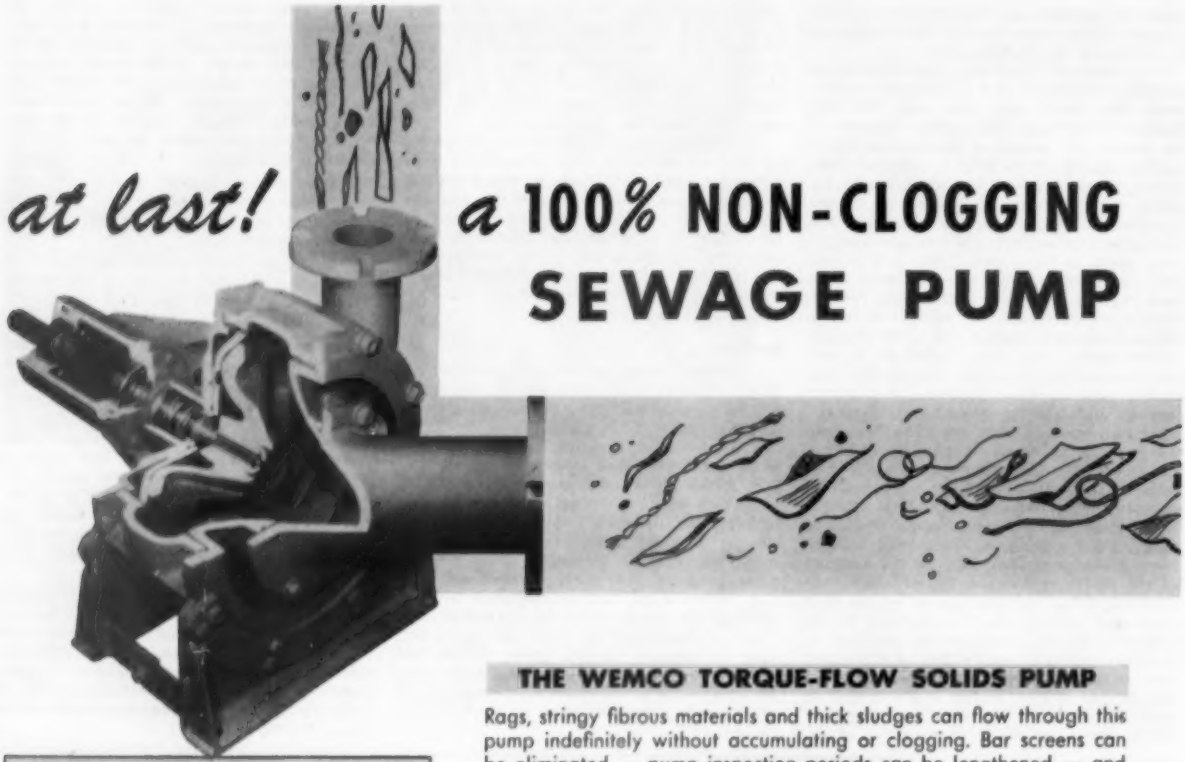

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COMPLETELY NEW IN CONCEPT

Success of the Wemco Torque-Flow Solids Pump is due to its unique new principle. Nowhere is its flow passage narrower than the discharge — and there are no rag catching projections, corners, or edges. The impeller is recessed from the main flow. It pumps by inducing a vortex and swirl. It will create suction lifts greater than 20 feet or pump heads of 100 feet and more.

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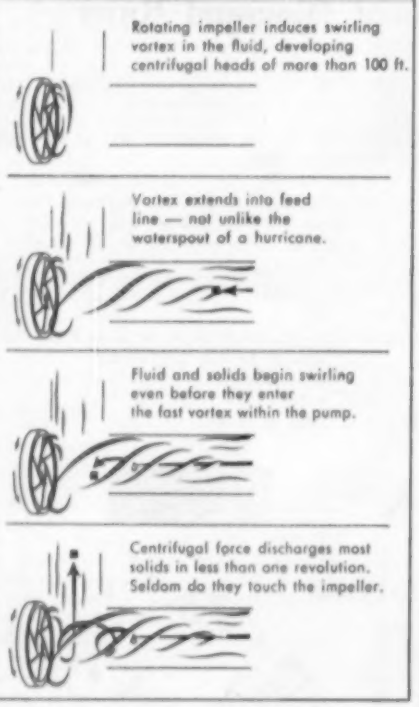
Rotating impeller induces swirling vortex in the fluid, developing centrifugal heads of more than 100 ft.
Vortex extends into feed line — not unlike the waterspout of a hurricane.
Fluid and solids begin swirling even before they enter the fast vortex within the pump.
Centrifugal force discharges most solids in less than one revolution. Seldom do they touch the impeller.

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ELECTRIC power is reliable, readily available, simple to obtain and relatively low in cost. It offers an excellent source of power for operating pumps, instruments, controls, chemical feeders and lighting and communication systems.

Definitions

To understand electricity and electrical equipment it is necessary to be acquainted with a few fundamental definitions.

Alternating current (A.C.) is electricity which flows from the generator in one direction for a definite period of time and then reverses and flows in the other direction for the same period of time.

Cycle or frequency is the number of times alternating current reverses its direction each second. Most common is 60 cycle, although some older systems are 25 cycle.

Direct current (D.C.) flows in but one direction. Battery output is direct current. D.C. can also be generated but is not used much.

Units of electrical measurement include: *Volt* (V), electrical pressure or potential; *ampere* (Amp.), rate of flow; *ohm* (R), resistance; *watt* (W) or *Kilowatt* (KW), electrical power. Electricity is usually sold on the basis of kilowatt-hours (KWH) or number of KW of power consumed times the number of hours involved.

Phase in alternating current refers to the time relation between current flow and the potential. Systems may be single phase (the current and potential reverse at the same instant) or poly-phase where the power is supplied from two or more generators operating on different time cycles (two phase cycles are 90 deg. apart; three phase cycles are 120 deg. apart).

Power Factor of a circuit is the ratio of the true power passing through it to the product of the volts times the amperes.

Load Factor is the daily (monthly, yearly) ratio of the average power to the maximum power used by a machine, plant or system.

Demand Factor is the ratio of the maximum load actually taken by an installation, to the total connected load (sum of ratings of all apparatus).

Equipment

In the design of water and sewage works, provisions must be made for receiving, conveying and using electrical power. Equipment includes transformers, switchboards, circuit breakers, motor, circuit and meters.

Type of equipment must conform to the type of electrical current available. Most power lines in this country carry three-phase, 60 cycle alternating current, but in some instances direct current is available.

Voltages used depend on type of equipment: 110 volts for lighting, small motors, and appliances. Larger motors use 220, 440, 550, 2200, or 4000 volts, depending on size; the latter two voltages are used for motors of 60-100 hp and more.

Types of Motors

In selecting electric motors, considerations should be given to: Suitability; speed, speed regulation, control, starting ease, current, and torque; power factor, rated power, partial load characteristics; and type of enclosure.

Types of motors include: Induction motors (both wound rotor and squirrel cage), and synchronous motors. The former may be obtained in single-phase and polyphase, with single phase being heavier, more costly, less efficient, more difficult to start but with a lower power factor. Squirrel cage induction motors are frequently considered as most suitable for driving water works pumps. Synchronous motors have low power factors, and higher efficiency but cost more originally than squirrel cage motors, and require a source of D.C. power for the exciter. They are usually used in sizes, 200 hp and over.

The design of motors depends on use and installation in many instances. There are open motors, partially enclosed, totally enclosed; drip proof, splash proof, water-proof, submersible, gear, brake, etc. Submersible motors are used with deep well and sump pumps. Motors may be direct connected, close coupled, or magnetic drive for connection to pumps, or may drive equipment from jack shaft or through gears.

Motor speed is an important factor in the selection of electrical motors. High speed motors cost less but slow speed motors are used for equipment that moves slowly like flocculators and clarifier rakes. Frequently the speed is reduced through a gear train. Variable speed motors find application with centrifugal pumps if the demand for water is not constant.

Installation

The setting of motors is important to the proper operation of both pumps and motors. The foundation must be large and stable enough to prevent vibration and must be level to prevent misalignment of pump and motor.

Transformers are used to step down the transmission line voltage to that of the equipment. As a matter of safety, transformers should be placed in fireproof rooms or at points protected from personnel traffic in water or sewage works.

Relays and circuit breakers are used to protect equipment, and to start and stop motors, pumps.

Switchboards contain the necessary devices to start and stop motors; close and open valves; operate relays; and house meters, recording and indicating instruments, etc.

In the installation of all electrical equipment safe practices must be followed. The National Electric Code Handbook contains details of standard practice; standard ratings of electrical equipment have been set by the Am. Inst. of Elect. Engrs.; and standards for electrical equipment and installation methods have been adopted by the Nat. Bd. of Fire Underwriters and the Amer. Stds. Assn.

Operation Problems

In addition to standard safety precautions with regard to personnel, there are a number of precautions to be taken to protect the equipment itself. Motors must be protected against too much or too little voltage; too much or too little load; reverse current, reverse power; reverse phase, lightning, current surges. Fuses or circuit breakers are used for overloads.

Motors should not be operated above an ambient temperature of 40°C, unless especially designed for high temperatures. Moisture and dust must be kept out of motors.

Motors should be started under full line current, but this is not always possible and special devices are used to protect the motor in starting. Where pump discharges are valved, an interlock switch is used to prevent starting the pump and motor with a closed discharge.

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*Material for this discussion is based in part on Chap. XIV on "Electrical Equipment" in *Water Supply Engineering* by Babbitt & Doland (McGraw-Hill).

COULD YOU LEARN TO CARE ABOUT...

power factor?

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"Mortimer Magnetizer is my name. Nobody has ever actually seen me, but anywhere electric motors are being used I get a powerful lot of work done!

"What I do is really simple—I set up the magnetic fields in the motors, and until I get going nothing much happens in your plant.

"Now, that's all well and good. I like my work. But it's the *Power Factor* business that bothers me. Because of *low* power factor in many plants, I get a lot of blame that's really not my fault. Honestly.

"You see, many plants use a goodly number of induction motors, and I like to magnetize them . . . they're hard workers. But unfortunately the reactive kva which I must have to magnetize is not produced by an induction motor. Instead, I must draw it from the main power system, and in a plant full of induction motors I can really 'overdraw' my account!

"This means the incoming power system must carry *two* things—*kilowatts* for useful work by the motors, and plenty of *reactive kva* for my magnetizing. The more of the latter, the less of the former, and brother, that's *low* power factor. It's expensive, because the 'deadhead' reactive kva can't do the work you want done, and yet you pay for it.

"What's the answer? Why, it's simple. The answer is Synchronous Motors. Use them wherever possible! They not only supply their own reactive kva for my magnetizing, but they can even be designed to supply extra or 'leading' reactive kva to offset kva demands elsewhere on the line.

"Now here's Utopia for me! When you use Synchronous Motors to supply reactive kva, you can reach a glorious state called UNITY, in which no costly reactive kva is required from the power system. Brother, that's *high* power factor, and that's how I work best!

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Practical Electricity in the Plant

By MARSDEN C. SMITH
Chief Engr., Dept. of Public Utilities, Richmond, Va.

Volt Equals Pressure

THE VOLT is the unit of electrical *pressure*. Just as water pressure is measured in terms of pounds per square inch, electrical pressure is measured in volts. Voltage is sometimes expressed as the 'emf' which is an abbreviation of electromotive force. The usual symbol is E.

Much effort has been directed to standardizing electrical voltages (pressures), but still a "110 volt circuit" may actually range from 110 to 125 volts or even more. In fact, most residential demands supplied by public utilities as "110 volt" usually are 120 or 125 volts.

Larger current consuming devices such as ranges are built for 3-wire service; phase to neutral (ground) being "110 volts"; phase to phase being "220 volts." If the "110 volts" is actually 120 volts, then the "220 volts" becomes 240 volts.

Fractional horsepower motors usually are designed to operate from the 110 volt lighting circuits. Larger motors are available for 110, 220, 440, 2,200 and 13,200 volts. In existing installations, the voltage often is fixed by the original design; but in new installations motors up to two hundred horsepower generally are operated at either 220 or 440 volts. Larger installations warrant the advice of an experienced electrical designer to secure the best economy and safety.

Extra-heavy fittings and greater precautions are necessary when greater water pressures are used; so too, must greater care be taken both of life and property when greater electrical pressures are used. However, pressures of as little as 110 volts, in common use, *may prove fatal* and care should always be taken to avoid personal contact, especially when hands or feet are wet.

Incandescent filament electric lamps are highly sensitive to voltage change from that for which they were designed. Particularly is this true in its effect on the life of the lamp. For example; lamps rated for 110 volts and operated at 118 volts would increase the cost of lamp renewals by almost 300 per cent.

Fluorescent lamps while not as seriously affected by over-voltage, are subject to ballast failure and rapid loss of light output if started and operated at above their voltage rating. Of particular interest to the operator is the effect of humidity and temperature on these lamps, If the room temperature is 50° F. or lower, or if the humidity is above 70 per cent, then rapid depreciation and otherwise unsatisfactory operation is to be expected.

Electric motors are not nearly so sensitive to voltage change as are lamps; nor are heating devices—particularly those that are thermostatically controlled. Motors will operate successfully at applied voltages within 10 per cent above or below their rated voltage. Greater voltage variation will generally cause excessive heating or unsatisfactory operation.

Ampere Equals Rate of Flow

THE AMPERE is the unit of electrical *rate of flow*. We are familiar with the various measures of the rate of flow of liquids; gallons per minute, etc.; so we should think of the unit rate of flow of electricity as the ampere. In equations its symbol is generally I. In print, ampere is sometimes abbreviated to "Amp."

Larger pipes are required to carry larger rates of flow of water economically; so too, larger wires are needed to carry larger currents (amperes) economically. Small pipes may be uneconomical because friction causes too great loss of water pressure. In exactly the same way, wires may be too small for the amperage (current flow) and cause an uneconomical loss of electrical pressure (voltage drop).

There are no standard currents as in the case for the voltage rating of electrical apparatus. Each appliance, lamp, heating device, etc., takes from the circuit a current dependent upon its design and lack of resistance to flow. Motors require, for example, a current that varies with the load. Each electrical unit (except lamps) should have its normal current rating stamped upon its name plate. Lamp current is approximately determined by dividing its watt rating by its rated voltage.

However, there are certain appliances such as wire, fuses and switches that are rated in terms of the current they may safely carry; thus, currents to this extent are standardized. The plant manager should realize that these current ratings are fixed by the National Electric Code, and he should *never* permit greater current to flow through accessories than the limits established by this code. Oftentimes circuits are fused far beyond the rated capacity of the wire, which is supposedly being protected by the fuse. Such practice is both uneconomical and dangerous.

Most appliances, including motors, are connected between the supply lines, that is, in parallel. In this way the circuit voltage is impressed upon each appliance, causing a current to flow through the appliance in a quantity dependent upon its rating and load. These increments of current are added, hence the supply wires carry greater and greater total current nearer the source of power. For example: Five 1,000 watt lamps rated 100 volts each require 10 amperes. Let us designate these as numbers one to five, from the nearest the supply to the most remote. Both wires between the supply and the first (No. 1) lamp carry 50 amperes; between 1 and 2 40 amperes, and so on until between 4 and 5 the current has reduced to 10 amperes, or that required by No. 5—the last lamp. They all have (practically) the same voltages as the supply applied to their terminals.

Ohm Equals Resistance

THE OHM is the unit of electrical *resistance*. In equations its symbol is R.

If we close the spigot, even though there is water pressure at the valve, no water can flow because the resistance is too great. The same result is obtained when opening an electric switch; the pressure (voltage) still exists but the resistance (ohms) become so great that no current (amperes) can flow. This is an example of localized resistance.

Electrical resistance may be distributed, in fact is distributed along the conductor just as is the pipe resistance to water flow proportional to its size, length and condition. Fortunately, in electrical circuits the loss of voltage (pressure) is always directly proportional to the resistance and rate of current flow. Therefore, the loss of power (to be discussed later) is proportional to the resistance and the square of the rate of flow or current.

An electrical device, such as a lamp, does not use or destroy current in the sense that an oil lamp consumes oil, but by its relatively high resistance limits the current that may flow as a

result of the impressed electromotive force—voltage. Thus we have the simple but important equation known as Ohm's Law:

$$E = RI \quad \text{.....(1)}$$

There are no standards of resistance; however, the established resistance per unit length of electrical conductors and resistance alloys may be found in any electrical engineer's handbook.

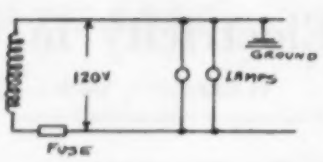


FIG 1

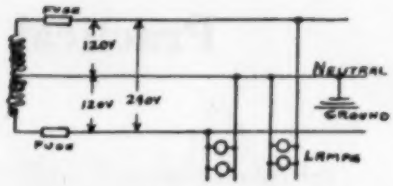


FIG 2

Circuit diagram—Figs. 1 and 2

Watt Equals Power

THE WATT is the unit of electrical *power*. The most commonly used unit is the Kilowatt, which is one thousand watts. The symbol for the Watt is W; for the Kilowatt KW. The mechanical unit of power is horse-power; one horse-power (HP) is the equivalent of 746 watts or 0.746 kilowatts. Due to the fact that the efficiency of small motors is approximately 75 per cent, the input in kilowatts is, by coincidence, closely the same as the mechanical output in horse-power.

With direct current, electrical power is the product of the current (I) and the voltage (E). Thus we have:

$$P = EI \quad \text{.....(2)}$$

However, substituting for (E) from equation (1), wherein $E = RI$, we have:

$$P = RI^2 \quad \text{.....(3)}$$

Or similarly, substituting for (I) where $I = \frac{E}{R}$ in the same equation:

$$P = \frac{E^2}{R} \quad \text{.....(4)}$$

Now it becomes evident that electrical power varies directly with both current and voltage, if resistance is not considered, but as the square of either (E or I) if the resistance is considered.

Direct and Alternating Current

Formula (1) applies only to circuits that contain nothing but resistance, no inductance or capacity; or those circuits in which the "frequency" is zero. If two wires A and B are left connected to the terminals of a battery, the current flow in the wires will be in one direction, thus becoming a "direct current" (unidirectional current). Such circuits usually are referred to as D.C. circuits and include battery supplied devices. These circuits are seldom used for public power except in limited areas of older cities.

If now we reverse the connections of the two wires each ½ second, then the current will flow in one direction for ½ second, but will flow in the reverse direction during the next ½ second. Obviously the current will then flow in the same direction in the same wire commencing once each second. Such a circuit would be defined as an "alternating current" (or voltage, or circuit) having a *frequency* of one *cycle* per second. Thus it is evident that "frequency" is the number of "cycles" per second, or ½ of the number of times the current flow reverses in each second.

The almost universal standard frequency is now 60 cycles per second, and the time-potential value of the voltage closely follows the sine law. This latter fact permits the use of vectors in the solution of alternating current problems, but such solutions are beyond the scope of these notes.

If a direct current is caused to flow through a coil of wire having a resistance of R ohms, wound around an iron core, then—since the frequency is zero — formula (1) can be used. But if the current is made alternating, the value of R seems to increase more and more as the frequency is increased. This is because the coil and its iron core form an "inductance" the nature of which is mechanically similar to a heavy fly-wheel. Inductance opposes any change of current flow and thus prevents the current from being proportional to the voltage (roughly speaking). If the coil has no resistance (academic assumption) then this inductive effect would cause the current to lag 90° behind the voltage causing it to flow. Parenthetically, "capacity" (insulated plates or parallel wires), which is an effect negligible in water plant installations, causes the current to lead the voltage by 90°. Thus, if the capacity effect is equal to the inductive effect, these cancel and the circuit behaves as if it contained neither capacity nor inductance.

Thus in an alternating current circuit, equation (1) becomes:

$$E = ZI \quad \text{.....(5)}$$

in which Z is the *impedance* of the circuit and its value is expressed in ohms.

Many electrical appliances, including heating appliances and lamps have little if any magnetic effect (hence little inductance) and so may be used equally well in alternating or direct current circuits. Motors must be of a special design if they are to be used on both AC and DC circuits; and transformers must never be connected to DC supplies.

Power Factor

The above equation (2) is generally used in the form:

$$P = EI \cos \Theta \quad \text{.....(6)}$$

In which the Cos Θ is the *power factor* of the circuit, sometimes abbreviated PF. The angle Θ is the time displacement between the voltage and the current which, as has been shown, is determined by the relative values of resistance and the inductive and capacity effect in the circuit. Since this may (theoretically) be of any value between zero and 90°, the power factor may have any value between zero and one.

The actual mathematical value of the power factor of circuits is difficult to compute, but may be readily determined by an instrument designed for the purpose or by the simultaneous readings of power, voltage and current by means of a wattmeter, voltmeter and ammeter.

As has been stated, the PF of heating appliances and lamps is quite

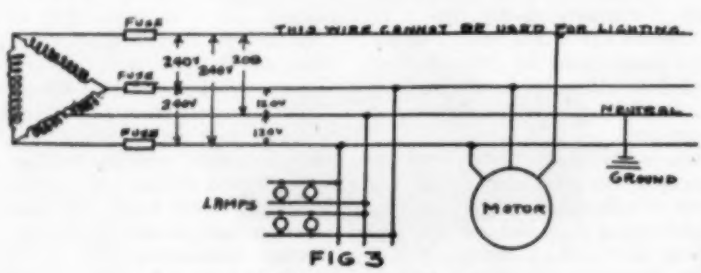


FIG 3

Circuit diagram—Fig. 3

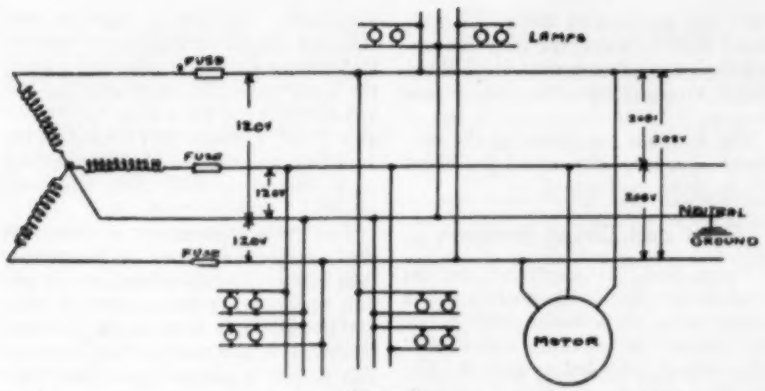


FIG 4

Circuit diagram—Fig. 4

nearly unity.

The PF of motors and transformers vary through rather wide limits, being nearly zero for transformers at no load. As their name implies, induction motors also have relatively bad power factors, small units being as low as 60 per cent at light loads and large motors of this type at full load not over 94 per cent.

Synchronous motors may operate at from 60 per cent lagging to the same value leading, thus cancelling the low PF of inductive units on the same circuit.

Low power factors are serious because of the greater current required for the same power, thus increasing the power loss in the wiring of the power supply. The effect on the constancy of voltage is also quite serious; in fact power companies frequently offer reduced rates to encourage the use of high power factor equipment.

Obviously the operator can do but little to improve the power factor of his system except in the selection of the type of motor, as more fully discussed later.

The Kilowatt-Hour

The kilowatt hour is the unit by which electric power is generally sold. As its name implies, it is the average power consumed, in kilowatts, multiplied by the number of hours involved. For example: if an electric iron is operated for two hours at an average rating of 600 watts, there is used 600 x 2 = 1200 watt-hours, or 1,2 KwHrs.

The volt ampere (VA) is the product of the volts and amperes of a circuit or an appliance, without reference to power. Thus, the transformer is always rated in volt-amperes (VA) because its parts can be designed for the voltage and current value desired, but the power-factor of its load determines its power output. Thus we see that:

$$KW = Kva \times Cos\ \theta \quad \ldots\ldots (7)$$

Hence, if we are to know the safe load for a transformer rated at 100 KVA, we must first determine the power-factor of the load to be connected. If we may assume one-half of the load to be lamps and one-half small motors, we may approximate the average power-factor as 82 per cent. Hence, by equation (7) we find Kw = 100 x 0.82 or 82 Kw to be the safe load for this case.

Grounding

Grounding is the connection of one wire of an electric system or any metallic part of the system to the earth.

All alternating circuits must be grounded, and the grounded wire is called the *ground* or *neutral*; the wires not grounded are called the *hot* or *phase* wires. The neutral is the point of equal potential to the phase wires (See Figs. 2 and 4). The neutral of Fig. 3 is neutral to the two bottom but not the upper phase wire. If there were no ground of the transformer neutral or of the phase wires in Fig. 3, the neutral would be an imaginary point.

The ground must be equal in size or larger than the phase wires; and it must not be fused or connected to any switch, and the wire used for the neutral must have white covering for identification, and the neutral must be connected to the white screw in all receptacles. In the single phase, two-wire system one of the wires must be grounded and the same rules as given for the neutral conductor wire must be observed.

The approved maximum voltage to ground for any wire connected to standard "house-wiring" switches and receptacles is 150 volts. This is why only one phase of a 220 volt delta system may be used for the lighting circuits. Where greater voltage exists for motors etc., the wires must be enclosed in a metal conduit and the frames of the motors and conduit system electrically connected and grounded. Grounding should be carefully inspected at sufficiently frequent intervals to make certain that the essential protection it provides is in perfect condition.

Grounds should be carefully made, preferably use not less than No. 2 B&S gauge copper wire. Several grounds are preferable to a single ground in order to lessen the chances of broken connections. Use the water pipe system; the larger the pipe, the better. Do not use the gas, gasoline or oil pipe lines. Be sure the connection between the wire and pipe is electrically and mechanically as perfect as possible. If no pipe system is available, drive at least three 1¼ inch pipes, or equivalent copper rods, *well below the moisture line* in the earth. A good test is that the driven ground connection, when shorted, should blow a 30 ampere fuse at 120 volts.

The necessity for grounding the electric circuits is to prevent dangerous high potential voltages (through mistakes or accidental contact) from increasing the normally low-potential circuits to a dangerous value. The wiring for lighting systems of buildings is designed for a maximum 150 volts to ground. Let us assume that a street series circuit operating at 5,000 volts should fall across the service wires from the pole to your home. With no ground on the "neutral" of your secondary wiring, its potential would be raised from its normal low value to a maximum of 5,000 volts. Certainly something must happen; either a fire would be started, or perhaps a member of your family would be killed. Now consider these same conditions to exist, except that now your "neutral" is properly grounded. When the high-potential circuit is now temporarily crossed with service, the high-potential currents are safely carried to ground, and no one in the home would realize the possible disaster that the ground connections have prevented.

Phase

Phase is a term also applied to designate the circuits of an alternating current system. In the "Single-Phase" system the *voltages* are in the same time-phase in all parts of the system. In the "Two-Phase" system, the two voltages are 90 degrees apart and in the "Three-Phase" system they are 120 degrees apart.

In another sense, it may be considered that there are in effect one or two or three circuits in the single, the

two or the three phase systems. Of course the load and power factor in the different phases may differ, and hence the computation of power in polyphase circuits becomes difficult and beyond the limits of these fundamentals.

Circuits

The single phase, two-wire circuit shown in Fig. 1 is the simplest and most used connection. As seen in figures 2 to 4, it is the connection used to supply lamps and small motors and appliances in even the largest systems.

The single phase, three-wire circuit shown in figure 2 is really two single phase circuits with one wire in common. It is used when more power is needed than can economically be supplied by the two-wire system; also it permits "220 volt" units to be connected to the two fused wires and yet the system has no more than 110 volts to ground. When the loads are identical the neutral wire carries no current, but since one fuse may *blow* (melt) the neutral must carry the same current as the phase wires and hence must be of the same size. But even then this system saves one of the four wires that would be required for two two-wire circuits.

The three phase circuits shown in Figs. 3 and 4 are really three single-phase circuits connected together, with the important difference that the three phases are equally spaced in time relationship (120° apart). There are two connections generally used for three phase circuits, the "Y" and the "delta," each of which has certain advantages. In general the "delta" is more reliable, when used for power only, in that if one transformer is lost the remaining two can supply 87 per cent of their combined capacity. But to off-set this when lighting is needed, unless the motor load is small enough to be operated at 110 volts, one of the neutrals of one of the transformers must be grounded, thus increasing the chances for power failure.

Then, too, many power companies will limit the lighting load that may be placed on the one phase supplying it (see Fig. 3); and the lighting is badly affected with "flickering" particularly if the motors are frequently started and stopped as for elevators.

The "Y" connection has the advantage that the lighting load can be divided between the three phases, but the three-phase voltage for motor use is less than that for which motors are usually designed.

Hence it may be said that for large loads three phase systems are always used. In one water treatment plant the lighting and motors of less than 5 HP are supplied by three "Y" connected transformers; the large motors and elevators are supplied from three DELTA connected (480 volt) transformers.

The formula for power in the different systems, with equal load and PF, is given in Table 1.

Fuses and Circuit Breakers

Fuses and all electrical circuit-breakers are similar in function to the safety valve on a boiler; and hence they should be seriously considered. They are all intended to open the circuit, thus stopping the flow of current, should the current exceed a pre-determined or dangerous rate.

While the problem of circuit protection becomes at times quite involved, still there is much that can here be discussed to advantage. The National Electric Code is now almost universally accepted as the authority for the safe utilization of electricity in all except central station systems. Consequently, the engineer should obtain a copy of this useful and important publication.

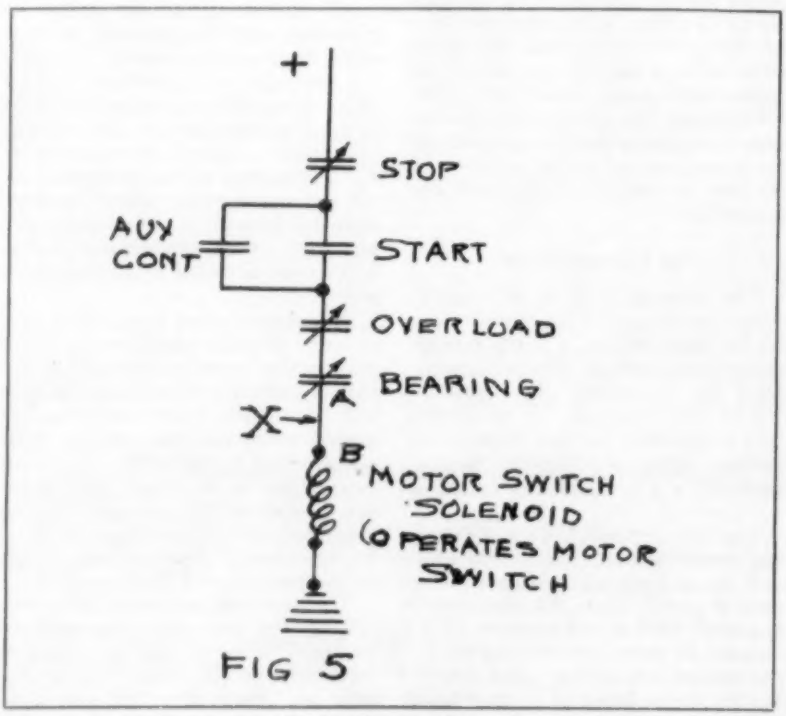
Fuses are the cheapest and simplest of all protective devices. They consist of a piece of relatively high resistance alloy wire or tape, designed to melt, and thereby part, at the current at which the fuse is rated. The wire is enclosed in a suitable flameproof case to prevent ignition of surrounding materials at the time the fuse flashes and melts. The use of fuses is now confined almost entirely to circuits the importance of which does not justify the more expensive and accurate devices. The type known as the "refillable type," permits the renewal of the fuse link and the use of the expensive part (the cartridge) over and over again.

For those applications in which the replacement of fuses is frequently necessary, thermal relays or air circuit breakers are recommended. Motor circuits fall in this classification. Thermal relays and circuit breakers can permit a greater than rated current pass for a short time, as during the starting period of a motor, and therefore are of especial advantage for this service. The current capacity as well the voltage ratings of this class of protective devices are limited, and when greater limits are needed the oil circuit breaker may be used.

The oil used in circuit breakers must be especially selected for this service; and no other oil should ever be used. This precaution is essential for the reason that the oil must have high insulation value, high flash point, low carbon content, and wide temperature viscosity constant—all in order to quickly quench the arc that is formed with each opening of the contacts.

Relays

The overload operation of a circuit breaker is usually actuated by an



Wiring diagram—Fig. 5

auxiliary device known as a relay. Relays may be of several types: the instantaneous, the inverse time limit, and others. The modern relays are truly marvelous devices; however, the types needed by the water works plants are only three:

(1) *The Instantaneous Type* — dash-potted relays with direct mechanical trip. Here a coil which carries all or a definite part of the load current raises a solenoid when the current flow exceeds a predetermined value. The rising solenoid mechanically releases a trigger, which in turn permits the circuit breaker to open. An oil-filled dash-pot retards the solenoid movement. The dash-pot opening is adjustable, hence the time for opening with a given over-current can be selected as desired. The oil in the dash-pot should be inspected at intervals and replaced if dirt or sludge has accumulated. While rather crude, this device is sufficiently accurate for the protection of most small motor circuits.

(2) *The Air Bellows Type.* Here an air bellows with an adjustable escape valve is used in place of the oil dash-pot described above. This type is now essentially obsolete.

(3) *The Induction Type.* This relay is more expensive than those above mentioned, but its use is justified in the protection of all important circuits. The advantage of this type is that the time of opening the main circuit breaker can be determined to a fraction of a second; also, the limits of control are so wide that these relays, with suitable current transformers, become almost universally applicable and highly accurate protective devices.

To repeat, too much care cannot be given the subject of circuit protection. Over-fusing (use of fuses with too great capacity) of circuits is dangerous and uneconomical. A too frequent operation of the overload protection of any appliance warrants prompt investigation. The source of the trouble should be remedied by correction, rather than following the easiest path of enlarging the circuit protection.

Motors

Alternating current motors are of two general types: the synchronous and induction. The main difference between these two types is that, while the synchronous motor can run only at a definite constant speed (synchronous speed), the induction motor must operate at a speed dependent upon the load applied, but never at synchronous speed. There are other important differences which will be mentioned later.

Synchronous Type Motors

At a given frequency the speed of a synchronous motor may be determined by the equation:

$$N = \frac{120f}{P} \quad \text{.....(8)}$$

in which N = revolutions of rotor per minute (RPM); f = frequency in cycles per second; P = number of poles.

Since the standard frequency is 60 cycles per second, equation 8 is generally expressed in the form:

$$N = \frac{7200}{P} \quad \text{.....(9)}$$

From this it is evident that the maximum speed for a 60-cycle motor is 7200/2 or 3600 RPM, and the speed, N, from equations 8 or 9 is known as the synchronous speed of the motor. This, for 60-cycle motors, is the constant 7200 divided by the number of poles; and since the number of poles must be an even number, synchronous speeds become 3600, 1800, 1200, 900 . . . RPM. One of the greatest limitations of the standard synchronous motor is that it cannot be built to operate at other than synchronous speeds, when oftentimes an intermediate speed is needed.

Unfavorable Characteristics

The necessity for this auxiliary direct current is indeed unfortunate, because direct current generators are difficult to maintain. Hence, greater skill and maintenance are required for synchronous than for induction motor operation.

Favorable Characteristics

On the favorable side of the ledger, the synchronous motor does possess the ability to operate with a "leading" power factor, contrasted to the rather decidedly "lagging" power factor of the standard induction motor. As has been stated previously, many power companies offer a lower rate to consumers whose requirements constitute a desirable power factor. Where this is the case, the ability of the synchronous motor to operate at the "leading" power factor may have influence in the selection of the type of motor to be adopted.

Induction Type Motors

The induction motor differs from the synchronous type in that it requires no separate excitation and it operates at a variable speed, as contrasted to the constant speed synchronous motor.

At no load an induction motor will run almost up to its synchronous speed. It should be understood that while the induction motor has no salient poles, the stator is wound to produce two, four, or any even number of poles, just as is the stator of a synchronous motor; hence, it has a synchronous speed of 3600, 1800, 900 RPM, just as does the synchronous type.

Favorable Characteristics

Standard induction motors have very favorable starting characteristics, requiring a relatively small starting current and producing 200 or more per cent of full load torque. They are the most rugged and reliable of all motors. But, while they will operate successfully under most adverse conditions, reasonable care should be taken to keep the air ducts and windings free from lint and dirt. The oil in the bearings must be flushed and changed at least once each year.

Variable Speed Motors

The wound-rotor induction motor, for operating at variable speeds, is not as rugged as is the standard squirrel-cage type. It is more expensive and also usually less efficient. A misunderstanding of the speed characteristics of these motors has caused no end of trouble.

We may gain a clear conception of the speed variation of the wound rotor, induction type motor if we think in terms of slip. As stated above, the standard squirrel-cage motor slip varies from virtually nothing at no load to about 3 per cent at full load. With the wound motor, external resistance may be added to the rotor circuit, the effect of which is to *increase* the slip. Hence, this motor will run at essentially *constant* speed at no load, regardless of the amount of external resistance introduced in the rotor circuit. But, as the load is applied, and the greater is the external resistance, the more rapidly will the speed be reduced.

TABLE 1

System	Power		Max. Volts to Ground
Single-Phase (Two-Wire)	$P = EI\cos\theta$	Here $E = 120$	120
Single-Phase (Three-Wire)	$P = EI\cos\theta$	Here $E = 240$	120
Two-Phase (Four-Wire)	$P = 2EI\cos\theta$	Here $E = 120$	120
Three-Phase (Delta)	$P = \sqrt{3}EI\cos\theta$	Here $E = 240$	207.8*
Three-Phase (Y)	$P = \sqrt{3}EI\cos\theta$	Here $E = 207.8$	120

* Volts to ground on lighting circuits is 120.

The two-phase (four-wire) system is so little used that no discussion is necessary.

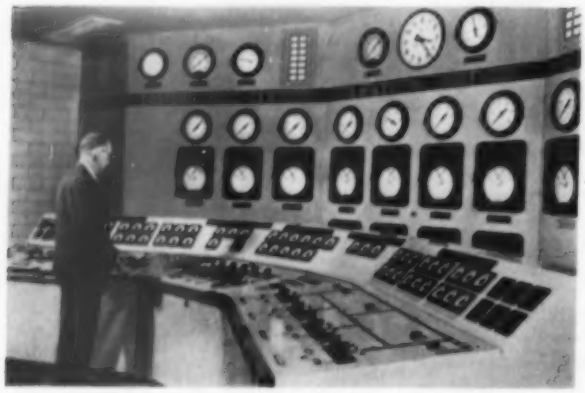
METERS : GAGES : CONTROLLERS
for Sewage Treatment and Water Supply

BAILEY METER COMPANY

1072 IVANHOE RD., CLEVELAND, OHIO

Bailey Meter Company Limited, Montreal, Canada

Atlanta	Charlotte	Cleveland	Detroit	Los Angeles	New Orleans	Pittsburgh	Seattle
Boston	Chicago	Dallas	Houston	Memphis	New York	San Francisco	St. Louis
Buffalo	Cincinnati	Denver	Kansas City	Milwaukee	Philadelphia	Schenectady	St. Paul



Centralized control room in a pumping station using desk and vertical-type panels.

CENTRALIZED CONTROL

The use of centralized control rooms in water supply and sewage treatment plants helps designers to secure fully co-ordinated operation and greatly reduced man-power requirements. When planning centralized control installations you now have available a line of Bailey products developed especially for this service. These products which are described in Bulletin 17-F include:

1. Bailey Pneumatic and Electric Transmitters.
2. Bailey Receiver-Recorders and Indicators.
3. Bailey Pneumatic Control Components.
4. Bailey ARMORTUBE Cable for carrying Pneumatic Signals.

TELEMETERING SYSTEMS

Bailey Receiver-Recorder for pneumatic and/or electric signals.

Pneumatic and/or electric signals actuate Bailey Telemetering Systems. Either or both may be received in the Type WM55 Receiver-Recorder (Product Specification E12-5). Multiple receivers may be connected to one transmitter. Several flow measurements can be totalized on one record. Automatic control may also be part of the measuring and telemetering system.

For a complete list of factors such as flow, level, pressure, temperature, pH, conductivity, turbidity and speed which can be measured and telemetered, ask for Bulletin 17-F.

CHEMICAL FEEDERS

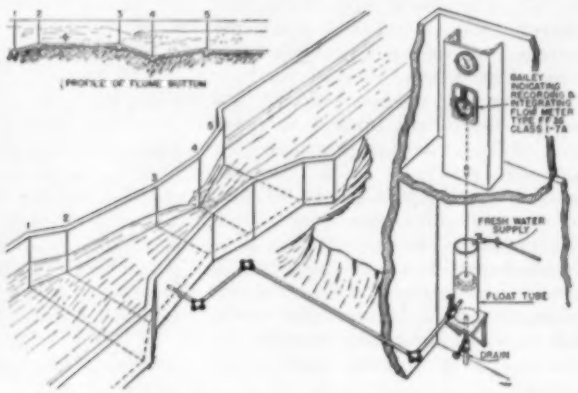
Electric or pneumatic signals from Bailey Registers may actuate chemical feeders, fluid sampling devices, alarms, or pump controls.

BAILEY REGISTERS

Mechanically operated register.

Bailey Registers measure flow of sewage, industrial waste, sludge, dirty water or other liquids in open channels or in pipelines. They also measure air flow, pH, liquid level in open and closed tanks and reservoirs and other factors.

Pneumatic and/or electric signals established by Bailey Registers may actuate automatic control systems.


PROFILE OF FLUME BOTTOM
BAILEY INDICATING RECORDING & INTEGRATING FLOW METER TYPE FF 55 CLASS I-7A
FRESH WATER SUPPLY
FLOAT TUBE
DRAIN

Typical installation of Bailey Flow Meter for Parshall Venturi Flume.

The following are typical applications:

. . . FOR OPEN CHANNELS

The Bailey Flume or Weir Meter is simple and accurate. As shown in the illustration above, it consists of a single float connected by a flexible cable to a sturdy indicating, recording and integrating mechanism, which may be mounted on a panel board, a wall or a column. Remote location may be obtained by the use of a Bailey Telemetering System. Ask for Bulletin M22-5.

. . . FOR PIPELINES

The Bailey Open Float Type Meter measures flow of sewage, sludge, dirty water, or other liquids in pipelines using venturi tubes, flow nozzles, or eccentric orifices. It operates through a differential gearing and cam mechanism from floats which rest on the liquid surfaces in float tubes.

The Bailey Fluid Meter accurately measures flow of steam, liquids, and gases in pipelines at high or low pressures. A venturi tube, flow nozzle or orifice is used as the differential producing device and the meter indicates, records and integrates on a standard Bailey Register. This meter may also provide records of pressure, temperature or liquid level on the same chart. Ask for Bulletin 301-B.

. . . FOR LIQUID LEVEL

Bailey Registers may be used in measuring liquid level in open tanks and reservoirs. Three methods are available:

Open Float Method—For location above liquid level.

Static Pressure Method—For location below liquid level.

Bubbler System—For measuring level or specific gravity of corrosive liquids and for liquids with solids in suspension. For more information on Bailey Level Recorders ask for Bulletin 17-F.

. . . FOR AIR FLOW

Bailey Air Meters measure air flow in main lines and in individual lines to aeration tanks. The register used is similar in appearance to the standard Bailey Fluid Meter and is designed to operate on a maximum differential pressure of 8" of water.

Air flow from a rotary positive type blower can be measured accurately with a Bailey Electronic Type Recorder measuring blower shaft speed by means of an electric tachometer. This may be calibrated to record in terms of air flow.

ARMORTUBE CABLE

Bailey Armortube Cable.

This protected multitube cable for pneumatic transmission lines minimizes installation costs and provides inherent hazard-proof protection for control systems. It is stocked in three sizes of 4, 8 and 12—¼" O.D. copper or aluminum tubes encased in heavy rust-resistant galvanized steel strip. Ask for Bulletin G91-9.

Flow Measurement in Water Works*

By GEORGE E. SYMONS, Ph.D.

Cons. & Tech. Editor, Larchmont, N. Y.

FLOW MEASUREMENT is a part of hydrodynamics. To understand it more fully, it is essential to understand some fundamental concepts and definitions.

Definitions

Quantity is volume contained in a confined space. *Flow* or discharge (Q) is quantity in movement past a point in a specified interval of time.

When a liquid moves in a pipe from one point to another, due to pressure (head), the quantity moving becomes the number of times the length of pipe (L) is filled and emptied in a given period of time (T). Since L/T equals velocity (V), therefore flow or quantity in motion (discharge) is

$$Q = A \times V \qquad \text{Eq. 1}$$

where Q = Vol. in cu ft per unit time (T)
A = Area of pipe in sq ft
V = Velocity of flow in ft per sec (or min) (T)

Velocity, or some function of it is a fundamental factor in flow measurement; therefore flow measuring devices are based on this concept.

Rate of Flow is the term applied to the measurement of quantity in motion for a relatively short period of time (e.g., per second, minute, hour, day).

Total Flow is the term applied to the total amount of liquid moved during a period of time, usually referring to a day, a month, or a year. Total flow equals the average rate of flow multiplied by time.

Units of flow commonly used in water works practice are: Cubic feet per second (cfs); gallons per minute (gpm); and million gallons per day (mgd).

Reasons For Flow Measurement

There are six reasons for flow measurement in a water works.

1. To provide data and information on plant production including rates of plant output as well as pressures in lines, total plant production for any period, rate of operation and total output of individual production

2. To provide information on operation efficiency, including unit operations, filters, filter washing, pumping, and well operation.

3. To provide control of unit operations, from flow measurements, including control of pumps, elevated storage tanks, chemical feeders, and filter operations.

4. To ascertain quantity of water sold wholesale to another supply, retail to individual consumer, and to determine non-revenue water.

5. To determine costs of operation including overall costs, costs per million gallons pumped, and costs of unit operations.

6. To provide records of permanence for health departments, management, or owners (either stockholders or taxpayers as the case may be).

Metering Points

The location of flow measuring devices depends on several considerations, but usually not on cost, since the total cost of meters is usually but a fraction of the total cost of a plant or system.

Individual points of flow measurement may include the following:

Source of supply—Letdown from reservoir storage, raw surface water intake, raw water pump output, both individual and total, and well field output, both individual and total.

Treatment—Flow from or to groups of coagulation and settling basins or softening units; wash water to supply tank; wash water to filters; effluent from filters, individual, groups, and total; finished water to clear wells.

Distribution—Gravity transmission mains and conduits; high service pump discharges, individual and total; elevated tank storage; and booster pump discharge.

Devices For Flow Measurement

Devices used for measuring flow may fall into one of six classes or categories: Head-area meters, functional meters, pumps, displacement meters, constant differential meters, and inertial flow meters.

Head-Area Meters are flow measuring devices used only in open channel flow or partly filled pipes; they cannot be used on lines under pressure, but are useful to measure flow from reservoirs. Head-area meters operate on the principle that a constriction or controlled barrier in the flow channel will back-up the liquid creating a higher level (head) than the level below the barrier, with that head being a function of the velocity of flow and therefore of the flow rate. Head-area meters include weirs, measuring flumes, and open end nozzles.

Functional Meters are mechanical devices which measure some function of volume in movement and which by means of other mechanical devices convert that measurement into rate of flow or total flow. There are three types of functional meters: *Differential head devices* produce a difference in head between two points of the device, and this differential is a function of velocity. These devices include the Venturi tube, Dall flow tube, insert nozzle, Gentile flow tube, and orifice. Differential head devices are used in main line metering and in metering flows at any point where water moves under pressure in a confined pipe.

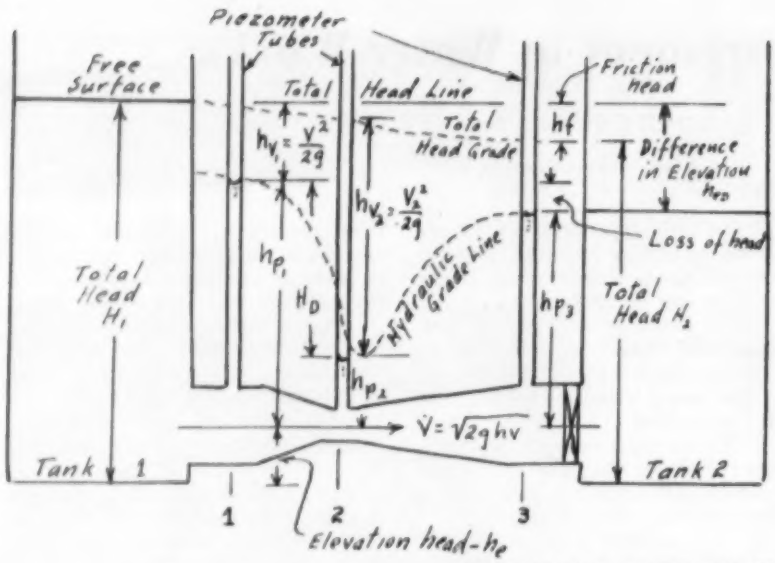
Velocity meters consist of a device by which a vane or propeller turns in direct ratio to the rate of flow past the propeller. These devices are used in main line metering, pump discharges, etc.

Pitot tubes consist of a vertical tube with a tip at right angles inserted in a flow, with the tip facing upstream. The height to which the fluid rises in the tube is a function of velocity and therefore of rate of flow. There are two other types of Pitot tubes.

Pumps may be used for measuring device, only if the number of repeat cycles can be determined. Controlled volume reciprocating pumps can be used easily for this purpose, but centrifugal pump discharges must be calibrated, for each speed of operation, suction lift or discharge head. Pumps are not generally used or recommended for flow measurement.

Displacement meters operate on the fill and draw principle. Fill and draw measurements of reservoirs and tanks can be made if the liquid entering or leaving the tank does not take place at the same time. When the fill and draw principle is applied to a closed device, a compartment is alternately filled and emptied. This is the

* Adapted from a lecture on "Flow Measurement" in a series on "Water Works Practices" in *Water & Sewage Works*, Sept. 1954, p. 395.



From B-I-F Industries Keep Sheet No. 23

Fig. 1—WATER under pressure flowing through differential producer

type of meter used for domestic water consumption.

Constant differential meters, commonly termed rotameters, consist of a tapered tube, smaller at the bottom than at the top, in which is confined a movable element termed a "float." The "float" rises proportionally in the tube as the rate of flow increases. This device is not used for measuring large flows, and has its greatest application in measuring gas flows.

Inertial flow meters do not measure volume, but determine mass by determining an inertia force of a moving mass.

Fundamentals of Flow Measuring Devices

Weirs, rectangular, trapezoidal, or V-Notch, are not used to any great extent in water works practice, but tables and charts are available to convert heads over weirs to "Q" values. (See *Wat. & Sew. Wks.*, 98, April 1951, p. R-182-R-183.) Open channel flow may be determined from measurements of heads at different points for different rates of flow and plotting rate of flow against depth of liquid. Formulas for open channel flow are not exact but give good approximations if the conduit or channel is well constructed.

Alignment charts and nomograms are available to make it easy to use these open channel flow formulas. See various Reference and Data Editions of *Water & Sewage Works* for these tables and charts.

Parshall Flume—The Parshall Flume is widely used for open channel flow measurements. It is an adaptation of the Venturi tube principle and requires exact construction limits.

The design consists of an entrance section with converging walls and level floor, a constricted throat section with parallel walls and downstream sloping floor, and a recovery section with diverging walls and rising floor. Stilling well and tap are placed in the converging section at a point two-thirds of the length of the converging section above the crest of the flume. The tap is at right angles to the wall at invert level. Dimensions must be held to close tolerances and to improve accuracy, liners of corrosion resistant material may be used.

Parshall flumes are useful where a minimum head loss is available. Accuracy depends on downstream elevation (height of surface above the floor) being held to less than a definite percentage of that upstream.

Differential Head Meters—In order to understand the operation of differential head meters it is necessary to refer to the general principles of hydrodynamics. In particular, the relations between elevation, velocity and pressure heads are important. Definitions of total head, elevation head, pressure head, velocity head, and friction head must be known in order to understand the functioning of differential head meters.

If water flowed through a smooth pipe without friction, the total head would be the same at all points in the pipe, even if the diameter or elevation of the pipe changed. When water flows in a pipe, part of the total head is converted into energy of motion (kinetic energy) capable of lifting the water to a height called the velocity head. If there were no friction, water flowing through a pipe between two elevations would have the same velocity as a body falling freely between those two elevations or $V = \sqrt{2gh_v}$, where h_v is the height fallen.

In any pipe, regardless of friction or variation in cross-sectional area of the pipe, an equal quantity of water must pass all points at the same instant. This is the principle of "Continuity of Quantity" and is fundamental in the operation of differential head meters.

If a constriction is inserted in a piece of pipe (as shown in Fig. 1), the theory of differential head meters can be understood. With the valve closed, water does not flow and water in the piezometer tubes stand at the same elevation as the free surface in Tank 1. When the valve is opened, water will flow because of the difference in elevations between the two tanks. Part of the total head will be converted to veloc. head at point 1.

The same quantity of water must pass points 1 and 2 during the same time interval; therefore the velocity at point 2 must increase proportionately to the decrease in cross section area. At the same time as the velocity increases, the velocity head increases and the pressure head decreases. The greater the velocity, the lower the pressure head at the constriction.

Therefore, the difference in pressure head between the inlet and the constricted portion of a differential head producer is a measure of velocity which is a function of rate of flow. The rate of flow varies as the square root of the difference in pressure at the two points. This difference is called "differential head" or simply "differential." The greater the differential produced the more accurate is the determination of rate of flow.

The increase in velocity is equal to $\sqrt{2gh_D}$, where h_D is the differential head and the flow formula derived from Equation 1 above, becomes

$$Q = A \times \sqrt{2g(h_D + h_{va})} \qquad \text{Eq. 2}$$

where Q = cu ft
A = cross section area in sq ft
h_D = Differential head in ft
h_{va} = Velocity head corresponding to velocity of approach at the inlet.

The velocity of approach cannot be observed but it can be converted into a *velocity of approach* factor expressed as $1/\sqrt{1 - \beta^4}$, where β is the Beta ratio, or ratio of diameter of the inlet (d) to the diameter of the

throat (D), (that is, $\beta = d/D$).

Because of friction, water passing through any differential head producer loses some energy. This loss appears as a decrease in head (h_F) and is known as "loss of head" or simply, "head loss" (See Fig. 1). Head loss means power loss or need for power to overcome the head loss. Therefore, the most desirable characteristics in a differential head producing device (often referred to as the primary unit) are maximum differential and minimum head loss.

Venturi Type Flow Tubes—The Dall Flow Tube is an accurate primary measuring device, which has the lowest permanent head loss (greater recovery of loss of head) of any known type of velocity-increasing differential producer. The Dall Flow Tube consists of a flanged cylindrical body designed with a short straight line section that terminates with an abrupt decrease in diameter, or "inlet shoulder." This shoulder is followed by a conical restriction and a narrow annular gap, called the slotted throat annulus. The annular gap is followed by a diverging outlet "cone."

The Gentile Flow Tube consists of a device with a slight constriction in the walls of which there are pressure nozzles or ports, some facing upstream, some downstream.

One advantage of Venturi type flow tubes is the short laying length and low weight. Other advantages are described in manufacturers' bulletins.

Orifices—An Orifice is a thin flat plate, in which there is an opening smaller than the pipe in which the orifice plate is inserted between flanges. A concentric orifice has a circular opening at the center of the pipe, an eccentric orifice has a circular opening tangent to the inside wall of the pipe. A segmental orifice has an opening bounded by the inner wall of the pipe and a chord of that circle.

The orifice is, in effect, a dam behind which solid particles will collect. Fluids passing through orifices show a permanent loss of head of 40 to 90 per cent of the differential head depending on the Beta ratio of the orifice (that is, the recovery is 10 to 60 per cent).

A slight increase in pressure occurs just ahead of an orifice; there is a sudden drop in pressure on the downstream side of the orifice and a continued pressure drop before recovery starts. The point of minimum pressure (maximum velocity) is known as the Vena Contracta. Full information on installation and use of orifices may be found in standard reference texts on hydraulics.

Insert Nozzles—A nozzle-like concentric throat section, smaller than the pipe in which it is inserted, is called an insert nozzle.

The simplest form is, in effect, an orifice plate with a cylindrical nozzle extending beyond the plate. It has many disadvantages of the orifice plate. Variations of the insert nozzle are designed to improve the recoverable loss-of-head. These include the ASME long radius nozzle, the Venturi Flow Nozzle and the Builders-Schlag-Jorissen Tube.

Selection of Primary Units

The device which measures the flow (weir, Parshall flume, open nozzle, Venturi tube, Dall flow tube, orifice, etc.) is called the primary unit. Considerations affecting the selection of primary devices include type of service, engineering factors, installation factors, accessories, comparative characteristics, and operators convenience.

Principal engineering factors to be considered include allowable permanent loss of head, size of the constriction, differential pressure, flow disturbance due to upstream and downstream conditions (bends, valves, etc.), distance to secondary unit, and type of transmitter required.

Selection of a primary measuring device can be simplified by comparing several characteristics common to all. These characteristics include: Accuracy, cost, capacity, range, permanent head loss, life expectancy, freedom from field tapping, freedom from upstream disturbances, ability to handle liquids containing solids, ability to handle high pressures, laying length, and ease of installation.

A table (Builders-Providence, Inc. Tech. Memo H4A) shows a comparison of all these characteristics on a per cent basis with 100 per cent representing the device having the best performance in the characteristic listed.

Secondary Instruments

A secondary instrument or receiver is the device used to convert measurements, sensed by and transmitted from the primary measuring unit, into observable information on flow. (Liquid level and pressure also can be shown on secondary instruments.)

Secondary instruments are classified in two ways—(a) According to type of information desired and (b) according to method of transmission from primary to secondary unit.

Classes by type of information desired include:

Indicator—Shows rate of flow, at moment of observation, in cfs, gpm, gph, mgd, etc.

Totalizer—Shows running total to time of observation, in cu ft, gal, mil gal, etc.

Recorder—Gives drawn record on chart, showing rate of flow as a continuous record for each instant during a particular period (hour, day, week).

Combinations are available as Indicator-Recorder, Totalizer-Indicator, Totalizer-Recorder, and Totalizer-Indicator-Recorder. Indicators have a single arm and dial. Indicator-Recorders may have the indicator arm separate from the chart, or indicator arm attached to the pen arm.

Classes by type of transmission include: Mechanical, electrical, pneumatic.

Transmission

Mechanical transmission exists when the receiver is operated by cables directly connected to float wells which are in turn connected to the pressure takeoffs (taps) of the primary device. Mechanical transmission also may be produced by connecting the primary device pressure taps directly to mercury wells in the receiver unit.

Electrical transmission is used where the receiver cannot be located near the primary unit or where there is insufficient pressure for direct connection of primary to secondary unit. Electrical transmission is of the time-impulse type (Chronoflo Telemeter) whereby the length of time that the signal is transmitted is proportioned to the magnitude of the function being measured, (rate of flow, pressure, level, etc.). This signal can actuate a receiving instrument, control pumps, chemical feeders or valves, or both. Electrical transmission is possible over any distance from feet to miles, over telephone circuits, private A.C. or D.C. lines, or multi-service wires. A sequencing unit (Sequence Unit Transmitter) will transmit signals from several transmitters consecutively over the same pair of wires. Sequencing is useful in the operation and control of well field pumps and booster pumping stations.

Pneumatic transmission is useful up to 1500 feet; it generally makes use of a varying controlled-air-pressure ranging from 3 to 15 psi. Principal features are absence of wiring, continuous output signal (pressure), extreme sensitivity to change in variable being measured, and in immediate response to change in variable.

Secondary instruments, their design, operation, and application, and their use in control functions are all part of the general subject of instrumentation and control.

Gentile

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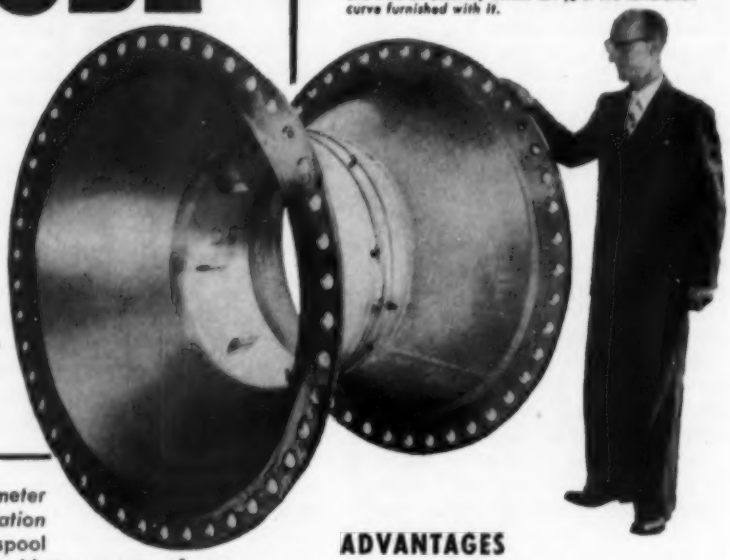
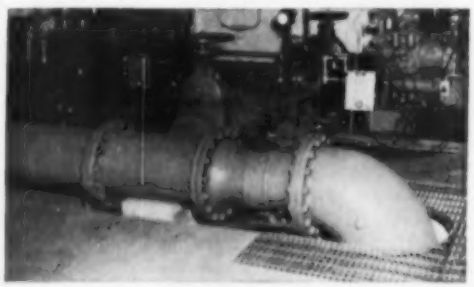


This 48" Foster Type D Flow Tube, of lightweight fabricated steel construction for measuring flow of air in the discharge line of a reactor air system, flanged for 125#, is only 48" in length between flanges and weighs only 1350 lbs. — many feet shorter and several thousand pounds lighter than a conventional venturi.

It is designed to handle 29,300 SCFM at 10.12 PSIA at 238°F with a maximum head loss of 2" H_2O and with an accuracy within ±1% of the calibration curve furnished with it.

The Gentile Flow Tube is an impact-type head meter designed for accurate measurement and regulation of fluid flow. It consists, essentially, of a short spool piece, the inner periphery of which is equipped with two groups of pressure nozzles, one group pointing upstream and the other downstream. The nozzle groups are inter-connected by common pressure rings from which connections are made to the high and low pressure sides respectively, of a conventional indicating, recording or integrating meter. Flow Tubes differ from other variable head meters in that the taps are located at points of equal cross-sectional area. Therefore, the differential developed is a function of the velocity head and independent of the static head.



Actual installation of a 16" Flow Tube for reverse flow. Note fittings (elbow and tee) bolted directly to flanges of Flow Tube.

Flow Tubes are available in all commercial pipe sizes with flanged or screwed connections. Standard lining is bronze, but other materials such as stainless steels are available.

Flow Tubes are used for the metering of raw water influent, plant effluent, filter effluent, filter wash water, and filter surface wash, as well as for shop tests of hydraulic equipment where accurate results are important.

Flow Tubes can be furnished with or without suitable secondary indicating, recording, or totalizing instruments.

Flow Tubes are manufactured exclusively by Foster Engineering Company. Write for your free Flow Tube Data File which gives full details.

ADVANTAGES

COMPACTNESS — No expensive vaults or large areas needed, because Flow Tubes are short. They are only about 1 to 1½ diameters long, depending upon the velocity in the main.

EASY TO INSTALL — Can often be installed with no straight run upstream or downstream, except when near valves or regulators. For more difficult arrangements, where extreme turbulence exists, tests may be run simulating actual conditions.

SIMPLE TO PURGE — Can be easily and quickly flushed without removing from the line.

FLEXIBILITY — Can be designed to handle high line velocities with low head loss and reasonably low meter differentials. And, they can be made to give a higher differential for a given diameter ratio than certain other types of head meters.

REVERSIBILITY — It's impossible to install a Flow Tube backwards — upstream and downstream sections are identical. Where system calls for flow reversal, the meter can readily handle the changes.

LOW HEAD LOSS — Flow Tubes can be designed with a D/d (main-to-throat) ratio to provide differentials that can be accurately measured with the least unrecovered head loss.

ACCURACY — Flow Tubes are furnished with head-capacity curves based upon laboratory tests, and can therefore be guaranteed as to accuracy.

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Primary Devices and Meters for Waste Flow Measurements*

By HOWARD O. HITE

Engineer, Instruments Division, Minneapolis-Honeywell Regulator Co., Philadelphia, Pa.

FLOW meters for waste measurement fall into two categories. The first class, differential head meters, is used for measurement in completely filled pipes and includes such primary devices as orifice plates, nozzles, and venturi tubes and a suitable differential pressure meter. The second category, known as head-area meters, is used for measurement of flow in open channels and partially filled pipes. Examples of this type meter are weirs and Parshall flumes.

As complete coverage of the subject would be exceedingly lengthy, this paper merely points out the advantages and limitations of each of the most commonly used devices as an aid in the selection of meters for specific applications.

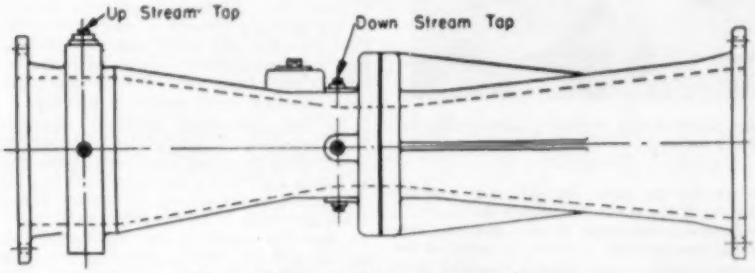

FIG. 1.—Schematic diagram of venturi tube.

Differential Head Devices

The differential head meter, as previously mentioned, requires that the pipe be kept filled with fluid for satisfactory operation. All primary devices for use with such meters are basically differential pressure producing resistances. As the fluid enters the resistance, the velocity is increased, with a loss in static pressure. It is this drop in static pressure that is measured as an indication of flow.

Venturi Tube

The venturi tube (Fig. 1) is the oldest of the modern primary elements. The designs used today are essentially the same as those used by Clemens Hershel in 1887. The venturi tube consists of a conical reducing section, a cylindrical throat section, and a diverging exit cone. The transitions from the entrance cone into the straight throat are rounded off by an easy tangential curve to avoid the resistance caused by a sharp corner and also preclude the possibility of cavitation. The differential pressure is measured between taps located slightly upstream of the entrance cone and at the throat.

When the venturi is used with clean fluids, a piezometer ring is usually used at both of these points to obtain the average static pressure at each point of measurement. For many sewage and industrial waste applications the piezometer rings are replaced by a single tap at each measurement point. With this arrangement, clear liquid purges may be used to keep the taps open. An alternate scheme, which is often used, is a manually operated cleaning valve.

The entrance cone generally has an included angle of 21° and the exit cone an included angle of 7°. This design gives the optimum pressure recovery. Usually about 80 to 90 per cent of the pressure drop at the throat is regained. Other angles have been used to reduce the length and weight of tubes, but this is done at a slight reduction of the pressure recovery characteristics.

Cast iron is the most common metal used for venturi tubes. However, special tubes of other materials may be obtained to overcome corrosion problems. Brass, bronze, stainless steel, concrete, and even rubber-lined tubes have been supplied.

The venturi tube has the following advantages over other differential devices:

1. Tapered approach and exit cones give lowest pressure loss.
2. For the same head differential and diameter, flow rates will be approximately 50 per cent higher than for an orifice.
3. There are no pockets where suspended particles in the solution may accumulate.
4. Long runs or straight pipe are not required.

The principal limitations of a venturi are its relatively high cost, large size, and lack of flexibility of range.

Flow Nozzle

The flow nozzle (Fig. 2) consists essentially of the entrance cone and throat section of the venturi, but has no recovery or exit cone. The upstream or high-pressure tap is made through the pipe wall at approximately one pipe diameter from the entrance. The low-pressure or downstream tap is located at the point of smallest jet area. The nozzle, which can be manufactured from most any material, has the following advantages:

1. It can measure 50 per cent more flow than an orifice.
2. Shorter meter runs are permissible than for an orifice.
3. It can be simply installed between pipe flanges.

The disadvantages are:

1. Although its cost is below that of a venturi, it is still much higher than that of an orifice.
2. Experimental work remains to be done in order to determine complete coefficients.
3. Not suitable for liquids containing solids in suspension.

Orifice

The orifice is probably the oldest device for measuring or regulating fluid flow. Records show that it was used to measure flow to householders in Rome during Caesar's time. Nevertheless, it did not receive real recognition as a commercial primary element until about the time of World War I.

The most common type of orifice is the concentric orifice. It consists of a thin flat

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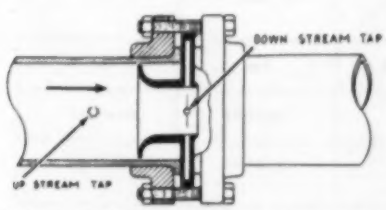

FIG. 2.—Schematic diagram of flow nozzle.

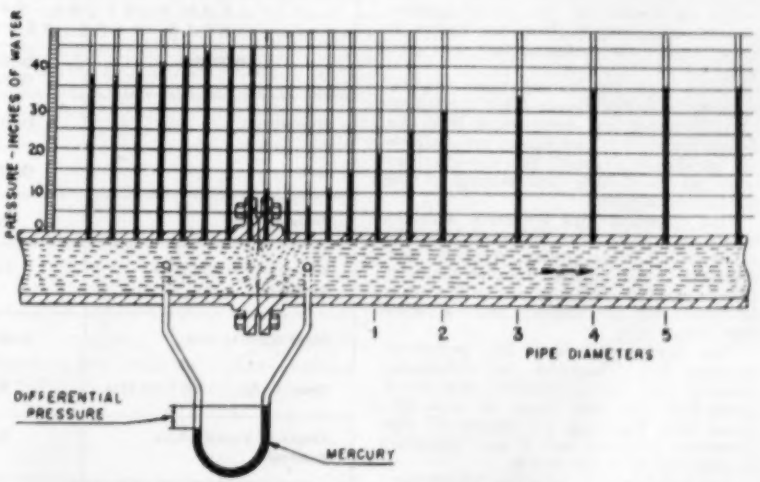

FIG. 3.—Pressure characteristics at a concentric orifice in a pipeline.

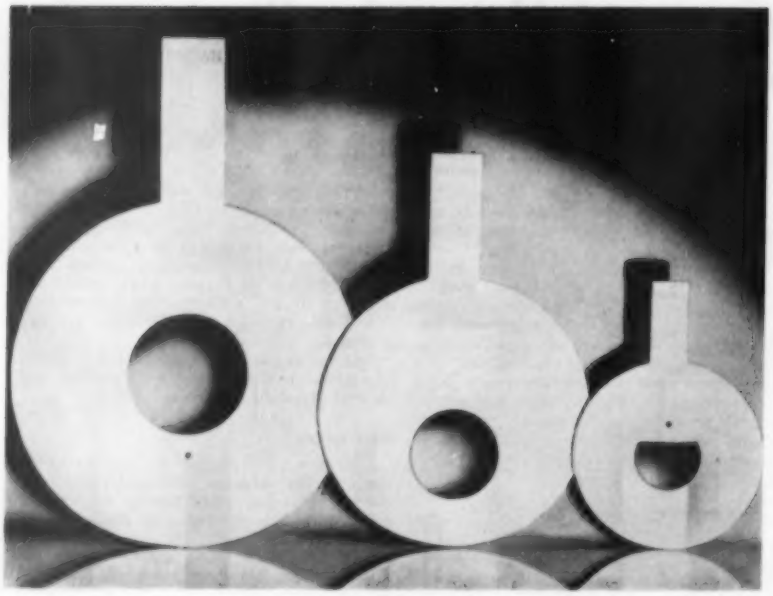

FIG. 4.—Types of pipeline metering plates now under study, including concentric, eccentric, and segmental orifices.

plate with a round hole, mounted between standard pipe flanges so that the hole is concentric with the pipe.

The Fluid Meters Committee of the American Society of Mechanical Engineers has spent considerable time and money studying the characteristics of flow through thin plate orifices. With the data obtained, orifice plates can be calculated and installed to measure flow with accuracy equal to that of the best venturi tubes. Orifice plates are usually made of stainless steel, although other materials such as glass and monel metal have been used.

Fig. 3 shows the pressure characteristics at the orifice. The pressure builds up slightly in front of the orifice, then drops suddenly on downstream side and continues to drop for a short distance along the pipe before the recovery starts. The point of minimum pressure and, incidentally, maximum velocity, is known as the vena contracta. It can be seen that the points at which the differential pressure measurements are taken are critical. For this reason, the Fluid Meters Committee has established orifice coefficients for the three standard pressure tap locations. These are known as flange taps, vena contracta taps, and pipe taps.

Flange taps are, as the name implies, made in the orifice flanges. They are spaced 1 in. upstream and downstream from the orifice. Standard tapped flanges are available and are simpler to install than the other two types, as no drilling and tapping of the pipeline is required.

Vena contracta taps are made with the upstream tap 1.0 pipe diameter from the orifice and the downstream tap at the vena contracta, usually about 0.5 pipe diameter from the orifice. These are not quite as easy to install, but are slightly more accurate than flange taps.

Pipe taps utilize only the permanent pressure loss. Therefore, the differential pressure will be considerably less for a given flow than with flange or vena contracta taps. Pipe taps are located 2.5 pipe diameters upstream and 8 pipe diameters downstream from the orifice.

The orifice has the following advantages:

1. The cost is low. For example, an orifice plate for a 6-in. line costs about $17. A nozzle for the same line will cost approximately $135; a venturi, about $375.

2. It can be made in any machine shop with conventional tools and installed between standard pipe flanges available from any piping supply house.

The disadvantages are:

1. The pressure loss is higher than that of a venturi.

2. Flow capacity is less than for a venturi or a nozzle; the exception to the rule is in the case of pipe taps, where the flow capacity is comparable to a venturi.

3. It is not suitable for liquids carrying solids in suspension.

4. Long pipelines are required in front of the orifice.

Work is now being carried on by the Fluid Meters Committee to determine coefficients for segmental and eccentric orifices (Fig. 4). In these orifices the opening is placed tangent to the bottom of the pipe. When these data become available the limitations regarding measurement of suspended solids with the orifice plate should be removed.

Fig. 5 shows a comparison of the principal application considerations for each of the primary elements discussed. Although it may appear that the principal advantage of the orifice over the other forms is its low cost, by proper design of orifice and selection of meter range the other objections of lower capacity and higher pressure loss can be overcome.

Differential Head Meters

All of the meters for measurement of flow through these primary elements are primarily differential pressure measuring devices. As such, they must contend with the fact that flow through any of these primary devices is proportional to the square root of the differential pressure.

The simplest type of secondary instrument is a variation of the common mercury manometer. A typical meter of this type is shown in Fig. 6. It consists of a float chamber, a range tube, and a connecting U-tube. The differential pressure created by the primary element is connected to the float chamber and range tube. In this design the float chamber is the high-pressure side of the manometer. This is not necessarily the case in all meters of this type.

As the differential pressure increases, the mercury level falls in the float chamber and rises in the range tube, causing the float to rotate a shaft in a pressure-tight bearing. This shaft moves the pen or pointer. Range tubes are made in an interchangeable series, so that the range of the instrument may be changed by merely replacing the range tube. This type meter has square-root charts and scales.

Other types of secondary instruments use cams, shaped range tubes, shaped bells, or other mechanical and electrical means to extract the square-root function and use uniformly graduated charts. Square-root charts give best readability and accuracy at the high end of the scale, whereas linear charts have improved readability at the low end. The choice of chart is primarily a matter of personal preference.

Secondary meters are available in a wide variety of forms. These include electric and pneumatic transmission, or direct-connected instruments. Indicating, recording, integrating, and controlling instruments can be obtained for almost any combination of these functions.

COMPARISON OF DIFFERENTIAL HEAD TYPE PRIMARY ELEMENTS

PROPERTY	CONCENTRIC ORIFICE	VENTURI	NOZZLE
Accuracy	Excellent	Excellent	Good
Cost	Excellent	Poor	Fair
Pressure Loss	Poor	Good	Poor
Suitability for Solids in Suspension	Poor	Good	Fair
Range Changing Ease	Excellent	Poor	Poor
Capacity for a Given Line Size	Good	Excellent	Excellent
Length of Straight Pipe Required	Poor	Excellent	Excellent

FIG. 5.—Comparison of Differential Head Type Primary Elements.

In specifiying instruments for a given application, the meter manuafcturer will insist on knowing all the conditions involved. If the application requires special consideration with respect to corrosion, head loss, or solids in suspension, he will advise the best form of primary element and meter for the particular application.

Head-Area Devices

In head-area meters, both the cross-sectional area of the stream and the head are variables, but not independently of each other; the area is a function of head. These meters are limited to measurement of liquid flow in open channels.

Parshall Flume

The most widely used primary device of the head-area meter type for sewage and industrial wastes is the Parshall flume (Fig. 7). It consists of an entrance section with converging walls and level floor, a throat section with parallel walls and downstream sloping floor, and an exit section with diverging walls and a rising floor. If the flume is properly installed in a channel, the rate of flow through the flume can be determined by a single measurement of the head or level made at a point one-third of the length of the inlet section from the entrance. A stilling well should be provided at the point of measurement to permit more accurate reading of the head.

The Parshall flume has the following advantages over weirs or other head-area meters:

1. It is easy to construct and may be made in a variety of materials (wood, sheet metal, or poured concrete).

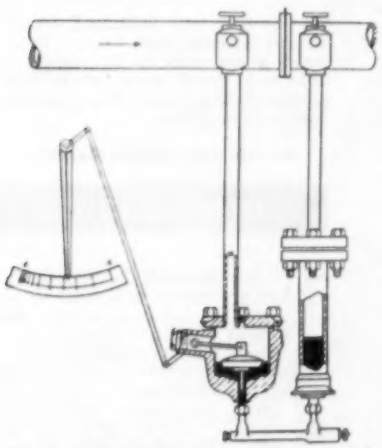

FIG. 6.—Simple differential pressure flow meter.

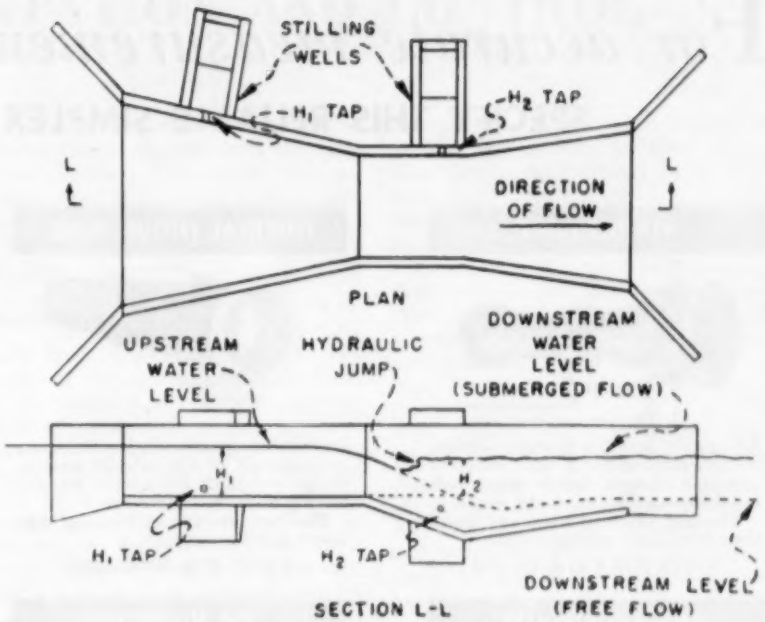

FIG. 7.—Basic elements of Parshall flume.

Although the weir is most accurate of the head-area meters, it has several limitations as a primary element for industrial use:

1. It requires construction of a weir box to obtain the proper flow approach to the weir.
2. Sediment in the fluid will settle in the weir box, with adverse effects on the weir calibration.
3. The loss of head through the weir will be equal to the head measured.

Kennison Nozzle and Parabolic Flume

Two other head-area devices in use today are the Kennison nozzle and the parabolic flume. They are both suitable for measurements of fluids containing solids in suspension. Like weirs, however, they must operate with a high loss of head compared to the Parshall flume.

Head-Area Meters

The measuring devices used for head-area meters are generally float actuated. Motion of a float riding on the liquid surface in the stilling well is transmitted to the instrument by a cable or tape. The instrument usually incorporates a cam or other device that extracts the proper function to give a uniform flow scale. These instruments are also available in the recording, indicating, and integrating forms of the differential head meters.

2. Solids in suspension are readily carried through the flume and do not affect the measurement accuracy.
3. Wide variations in capacity are possible. Flumes have been made with throat sections as small as 3 in. and as large as 50 ft.
4. The loss of head required for flow measurement is extremely small.

The only disadvantage of the Parshall flume is that its accuracy is not as high as that of a well-made and properly installed weir. Accuracy is generally stated to be within 2 to 5 per cent.

Weirs

A weir is a dam in a stream with a notch cut in the crest. The most common notches are rectangular, triangular, and a combination of the two, trapezoidal. Rectangular weirs generally are used for large flows where the variations between maximum and minimum flow are not too wide. The triangular weir is used for accurate measurement of small rates of flow and is particularly sensitive to changes in rate of flow at the low end of its range. The trapezoidal, or Cipolletti weir combines the features of both, having wider range ability than either.

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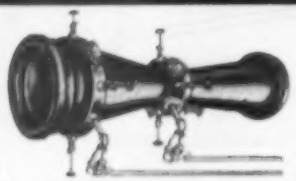

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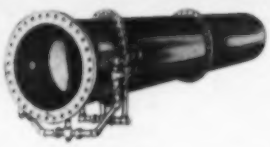

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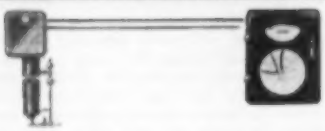

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INSTRUMENTATION AND CONTROL

SECONDARY instruments (or receivers) are devices which convert information sensed by and transmitted from a primary measuring device into observable information. Controls are devices which will receive information sensed by a primary unit and convert it into a control of some mechanical device, operation, or function, such as pumping, chemical feeding, flow regulation, filter washing, etc.

Secondary instruments (flow, level, pressure) are classified in two ways: Type of information desired, and method of transmission from primary to secondary unit. There are three types of information obtainable from secondary instruments, and these are obtainable either separately or in any combination. They are: Indication at the moment (as flow rate, level, pressure, temperature); totalizing over a period (flow); recording a drawn record on a chart as continuous indication of rates of flow, level, temperature and pressure. These secondary instruments are called respectively indicator, totalizer, and recorder.

Transmission

Secondary instruments are also classified according to method of transmission of information from primary unit to instrument. These are mechanical, electrical, or pneumatic. (Pressure is usually transmitted hydraulically.)

Mechanical meters are activated by float or directly by differential pressure. Electrical transmission is used where the receiver cannot be located near the primary unit or for other reasons. Electrical transmissions may be Chronoflo (time-impulse type) or other variations, and is good for any distance. Pneumatic transmission, by a varying controlled air pressure ranging from 3 to 15 pounds, is useful at distances up to 1500 feet. It features a continuous signal and immediate responses.

Summation and Ratio Metering

Two or more flow rates of pumps, mains or filters may be added together to give a total of the combined flow on a single receiver. This addition is accomplished by means of a summator (electrical or pneumatic) which receives the several sensed data and transmits the sum of the individual data. Ratio transmitters can be used to receive two different flows and calculate and transmit the ratio to a secondary instrument. This device is used in activated sludge plants to determine and indicate or record the air/sewage ratio and the return sludge/sewage ratio.

Receivers

In flow measurement, the flow varies as the square root of the head in the primary device. The receiver is designed to convert this information into the desired units. Charts or scales may be of the square root type with the divisions spaced according to the square of the unit. Readability is best at the high end of the scale. Linear type receivers have scales and charts with divisions spaced equally. Accurate readability is obtainable at both ends of the scale.

Controls

Flow measurement can be used to provide control of flows, chemical feeding, proportioning, pumping, sampling. Mechanical, electrical or pneumatic means can be used for control purposes.

Filter effluent controllers are available in two designs, self-powered, direct-acting; and hydraulic cylinder operated. They are used to maintain a constant rate of filtering regardless of loss of head as filters become dirty. Wash water controllers are similar to filter effluent controllers and are used to control the rate of filter back washing.

Auto-central control is a centralized system which automatically controls the rewash cycle of filters in sequence and can be initiated manually or by loss of head in the filters.

Chemical feed can be paced proportionally to flow at a fixed dosage rate, or by programmed schedule, or by timed-cycle. Sampling can likewise be controlled according to proportional flow, program, or time-cycle. Reservoir and elevated storage can be controlled by float or pressure sensing devices which control pumping. Distribution system flow can be controlled according to a combination of pressure and flow rate. (Pressureflo system.)

Operating Tables and Panels

Secondary instruments, also called receivers, or gauges, may be mounted in several ways. Loss of head gauges, rate of flow gauges, sand expansion gauges, and controls for filter operations are usually placed in a filter operating table. Wash water, and summated flow gauges are often hung in the filter gallery.

In centralized control, filter gauges, flow gauges, pressure gauges, and other types of receivers are placed in a single panel along with switches and controls, all of which may be located in the superintendent's or operator's office.

In sewage treatment works, flow measurement, disinfection, sludge measurement, sludge digestion pumping and withdrawals, sludge dewatering, elutriation, flow ratio-metering, and weighing of vacuum dewatered sludge all employ instrumentation and control. As in a water works, instruments and controls are frequently located in centralized panels, either in the operator's or superintendent's office or some other central location.

In both water and sewage works, centralized control reduces the work load on operating personnel, improves controls of operation and reduces operating costs.

Selection of Instruments and Controls

In the choice of secondary instruments there are a number of factors to be considered and many questions to be answered. In flow measurement, the type of primary device selected (weir, Parshall flume, Venturi tube, Dall flow tube, nozzle, orifice, etc.) dictates the method by which the secondary instrument or control is operated. The range of maximum to minimum flow must be known.

Accuracy depends not only on the primary device and the receiver but on the particular combination chosen. The relative location of primary device and secondary receiver has a bearing on the type of transmission used.

Choice of secondary instruments depend also on type of information desired, capacity of present plant, future capacity, and life expectancy of the equipment. Choice of primary and secondary instruments also have a bearing on control systems selected.

Selection of control systems and devices depend on the function, equipment, or operation to be controlled as well as the primary device, secondary instrument and system of control desired.

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Meters and controls engineered specifically for water, sewage, and waste plants . . . proven in thousands of installations.

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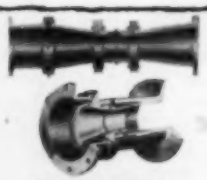
Propeller-type main line meter. Self-contained, easily installed. Can be used with indicating and recording secondary instruments, and to pace chemical feeders. Bulletin 380-K4.



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Industrial Waste Instrumentation

Practical applications of measurement and control

by JOHN J. BAFFA
Consulting Engineer, New York, N. Y.

Mr. Baffa's paper was presented at the First Conference on Instrumentation, Manhattan College, New York, and is here printed with permission.

PRESENT design practice in the field of industrial waste treatment in large degree utilizes instrumentation for measurement and control. Applications of instruments are found in all methods of wastes disposal, including discharge to municipal sewer systems, or to streams, or to ground waters. The industry may discharge wastes after complete treatment, or partial treatment, or no treatment.

Waste flows, fluid flows, liquid levels, temperatures and waste and fluid quality characteristics require measurement in order to:

(a) Obtain data upon which to base the design of collection, treatment and disposal facilities.

(b) Provide for operational control of treatment processes.

(c) Monitor waste-contributing processes, treatment plant influents and effluents, and receiving waters.

The use of instruments for these purposes also provides data for improvement of existing plants, for future design, for the dissemination of records, and for the stimulation of research.

Flow and Quality Variations

Industrial waste discharges generally are characterized by extreme variability in flow and quality. To measure these characteristics or to control them *manually* is, in many instances, humanly impossible; it certainly is subject to human errors, or dangerous, or expensive. Instrumentation provides the necessary tools to measure and control variations, eliminate human factors and save expense, all subject to the limits of present day knowledge, practicability and economy.

Industrial Waste Surveys

Instrumentation applications are especially useful in obtaining the data necessary to solve an industrial waste disposal problem. These applications include field measurements of waste flow and quality, quality measurements made in the laboratory, automatic recording of pilot plant flows, and pilot plant influent and effluent quality. In many instances, some of these measurements are necessary not only for the waste discharges but also for the receiving waters or municipal facilities.

The measurement of flow usually is accomplished by installation of a primary device such as a weir, orifice, Parshall flume, Venturi tube, positive displacement meter, or Pitot tube. Automatic recording of the flow, for a length of time sufficient to establish its peculiarities, provides basic design data. In some instances, several flow measuring units may be installed to measure flows from several of the manufacturing processes in the same plant, in order to permit calculation of component quality considerations. In this manner, leakage and losses may be revealed, isolated and corrected to reduce the volume of flow to be treated, and to increase manufacturing efficiency. Flow measurements also provide the necessary data or actuating means for manual or automatic sample compositing. Fig. 1 shows a waste flow pattern over a one-day period for a plant manufacturing cosmetics. The pattern is best described as being extremely variable over a wide range, as is characteristic of most industrial waste flows.

Quality determinations during the survey period may involve a number of instrument applications. These include recording pH meters and conductivity meters, recording temperature gages, turbidimeters, photometers and oxidation-reduction measuring devices.

Treatment Process Control

When complete treatment of waste is practicable, the use of instruments and control systems finds wide application to provide both uniformity of effluent and maximum operating efficiency.

Instruments are available to facilitate manual control of batch and of continuous waste treatment processes, and to provide automatic control of both batch and continuous flow processes.

Using flow meter and pH meter records which show a definite pattern, the operator can manually set chemical feed quantities as required. As a further step toward automatic control, chemical feed settings may be changed automatically by time clock controls. Where widely variable conditions are encountered, or

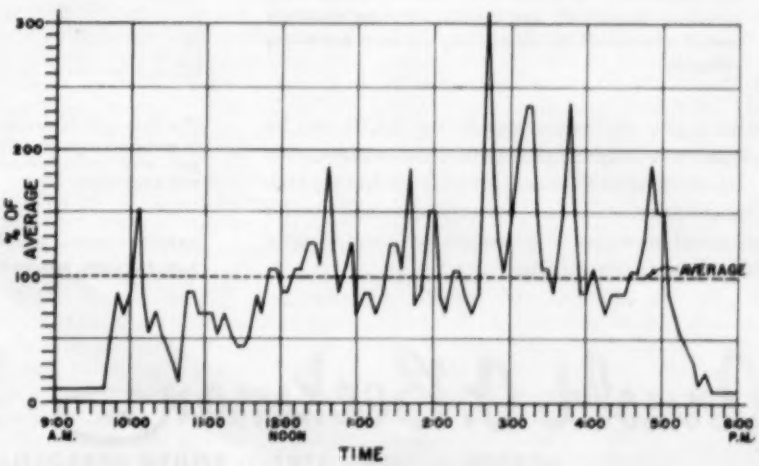

Fig. 1—ONE-DAY PATTERN of industrial waste flow for a cosmetic manufacturing plant.

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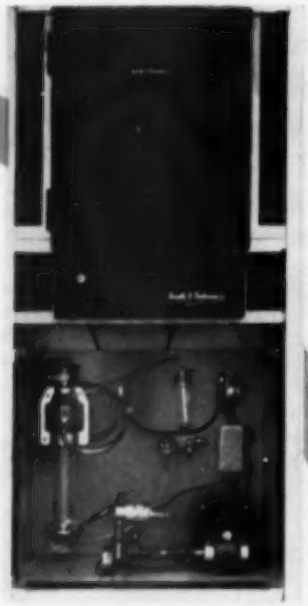

- Continuous record
- Handles fluids, slurries, sludges, etc.
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The Model 1A3B is a complete, compact unit—with the Analyzer in top compartment and the scrubbing unit below.

The accurate measurement of dissolved oxygen in fluid process streams is widely recognized as an important control factor in such municipal and industrial operations as sewage and water treatment . . . waste disposal . . . petro-chemical and chemical processes . . . food processes . . . and many others.

Now, you can make such measurements—continuously, simply and accurately—with the newly-developed Arnold O. Beckman Model 1A3B Dissolved Oxygen Analyzer!

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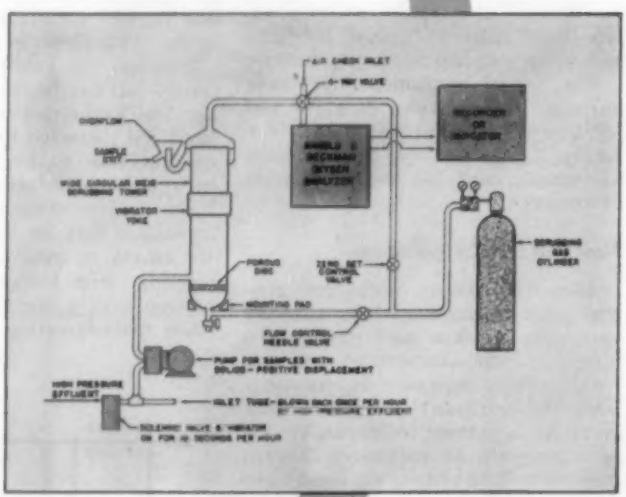
- **The Model 1A3B is factory-calibrated to read in percent saturation so that efficiency of aeration or deaeration is shown directly. Or if preferred, the instrument can also be supplied to provide readings directly in parts-per-million.**
- **The Model 1A3B can be directly connected to any standard potentiometer-type recorder or indicator. No special accessory equipment is needed.**
- **Using the Model 1A3B is far superior—in speed, accuracy and convenience—to conventional chemical methods—and provides—immediately and continuously—the necessary control information for maintaining optimum processing uniformity.**

With a few variations the Model 1A3B can be adapted to a wide range of application requirements . . . to handling sludges and other liquids having high concentration of solids . . . to handling samples under abnormal pressures or temperatures . . . and to other difficult sampling conditions.



The Principle is simple and positive. The constantly-fresh test sample in scrubbing tower is stripped of dissolved oxygen by inert scrubbing gas—and result measured by Analyzer. Measurement is continuous and accurate!

RANGES—from a maximum of 0-100% O_2 saturation to a minimum of 0-5 ppm, full scale. Intermediate ranges are also available.

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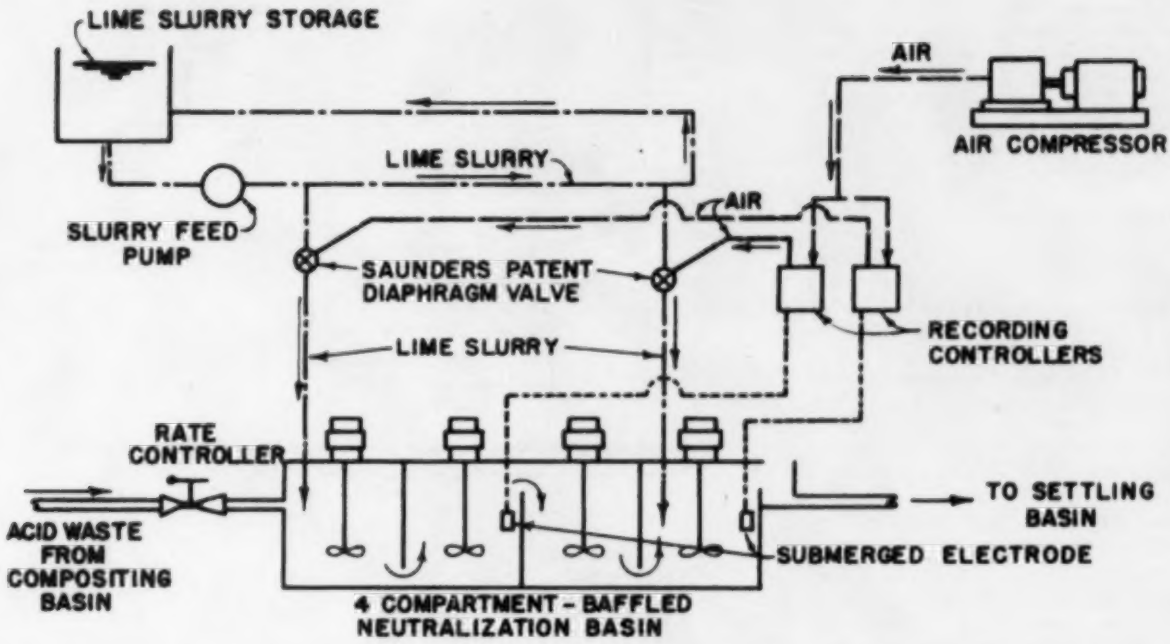

Fig. 2—NEUTRALIZATION of acid wastes. Scheme for automatically proportioning chemical solution feed on basis of pH value.

where considerable sensitivity of process is involved, then the automatic proportionment of chemical feed in accordance with pH, conductivity, or flow may be necessary.

The choice of instruments for any particular case depends upon the circumstances and economic factors involved and no general rules can be made.

Uniformity of effluent is important in many applications and can best be achieved by automatic proportioning of chemical feed, either according to flow or quality variations.

Operating efficiency, as a rule, is greatly increased by the application of automatic control to chemical proportioning. Manual labor costs are saved, human factors are eliminated, waste of chemicals through overdosage or possible corrosion through under-dosage are absent; and highly trained personnel, otherwise required to supervise manual operations, is left free for other tasks. Instrumentation applications providing for increased efficiency also include automatic flue gas sampling and automatic recording of conductivity or pH to indicate raw materials wastage.

Solution Feed Control

An example of proportioning chemical feed in accordance with quality variations is shown diagrammatically in Fig. 2. The application was made to neutralize an acid waste discharged from the manufacture of dyes. After compositing, a Simplex Valve and Meter Co. controller provided flow control to permit eight hour (1 shift) operation of neutralization facilities as well as to eliminate the flow variable. The basin dimensions chosen were based on reaction time determined in the laboratory, and the total volume was divided into four over-and-under type baffled compartments, each provided with a stirrer.

Two-point control was chosen in the interests of efficient reagent usage and maximum effluent uniformity, and also to prevent undesirable aftereffects in the receiving stream. Lime slurry was applied with continuous circulation, feed point take-offs being through Saunders Patent diaphragm valves pneumatically positioned. The recording controllers installed were Leeds and Northrup pneumatic controllers having proportional reset and rate action. Immersion type pH electrode assemblies having plastic heads were installed in the locations shown. The electrode assembly includes measuring electrode, reference electrode and temperature compensator.

With changes in pH at the electrodes, the controller automatically increases or decreases slurry flow through positioning of the diaphragm valve. The amount of increase or decrease of slurry flow is proportional to the extent that pH deviates from control point setting, and to the length of time that the deviation exists. Operation for several months indicates that with an influent pH varying from 3.0 to 4.0, the desired effluent pH of 6.0 can be maintained with little if any variation.

Dry Feed Control

In another application, shown diagrammatically in Fig. 3, lime feed is proportioned in accordance with flow using a Parshall Flume as the primary device. In this instance, flow changes are gradual, and quality of waste is relatively uniform. The recorder and transmitter were supplied by Builders Iron Foundry and the dry feeder by Omega Machine Co. The connection from the primary device to the transmitter is hydraulic, thence electrical impulses signal the solenoid at the dry feeder. The solenoid positions the belt-shifting device controlling feed rate. The float switch in the slurry tank is a safety precaution; it stops the feeder and the slaker discharge to the slurry tank if slurry lines clog and tank fill above normal level. Feeder and slaker will start when tank level recedes to normal.

Where flow changes are abrupt, and quicker response to flow changes is required, this same system is applicable except that belt shifting device would be eliminated and transmitter impulses would actuate a control valve on the slurry tank outlet, with slaker rate set slightly higher than lime demand.

Other applications of automatic control to industrial waste treatment plants include automatic control for digestion tank temperature and gas pressure, sludge conditioning pH, and operation of automatic bar screen and tank mechanism.

Monitoring Services

The monitoring function of instrumentation is of extreme importance for the following purposes:

a) To provide operator and community safety.

b) To safeguard receiving streams or municipal systems.

c) To provide a measured basis for municipal or sewer authority charges.

d) To provide records indicating that stream regulations have been met.

Instrumentation for safety purposes includes, automatic gas analysis for methane and inflammable or toxic gases, automatic recording of chlorine residual and detection of radio-active substances. Automatic recording of flow, effluent pH, conductivity and oxidation-reduction potential provide measures of effluent character. In all cases, alarm systems can be provided for instantaneous warning of treatment process failures, or manufacturing process failures, or losses which might affect treatment or disposal. The stream or receiving system is thus safeguarded. Instruments also protect an industry against charges of having discharged pollutants such as those which may cause injury. The study of recorded data can lead to elimination of waste and to improvement of process efficiency.

Modern developments such as municipal regulations which affect waste discharges to sewers, and sewer rental laws, have broadened the field of instrumentation application. Municipal regulations control the quantity and quality of waste discharges for the protection of sewers and of treatment plants (against deterioration and process upsets). In many instances, charges are made for handling industrial wastes. However, industries frequently find that disposal to municipal sewer systems provides an economical solution to their waste problems.

Fig. 4 illustrates an example of facilities for the controlled discharge of industrial waste, without pretreatment, to a municipal sewer system. The purpose of the design is to discharge a maximum of the waste during time of minimum sewage flow to a municipal sewage treatment plant. No pretreatment of waste is required as the waste forms no sludge in the holding tank. The rate controller is Builders Iron Foundry Model RCB. At a predetermined time set on the time clock, the rate controller is automatically opened to a previously set rate by the pneumatic control system. After a pre-set time interval, the controller is closed.

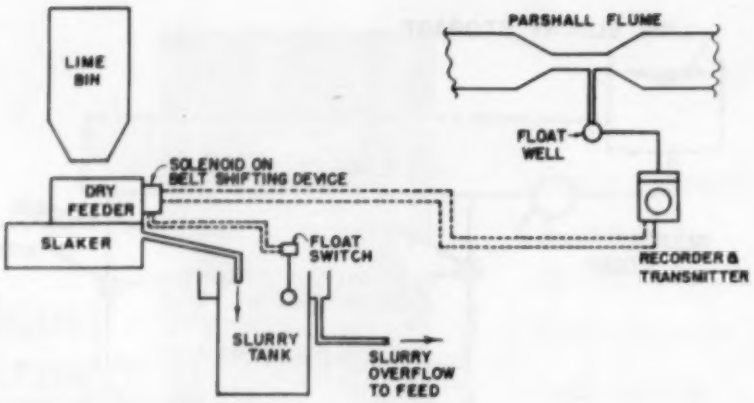

Fig. 3—COAGULATION of flue dust and waste. Scheme for dry feed control. Slaked lime is automatically proportioned on basis of waste flow.

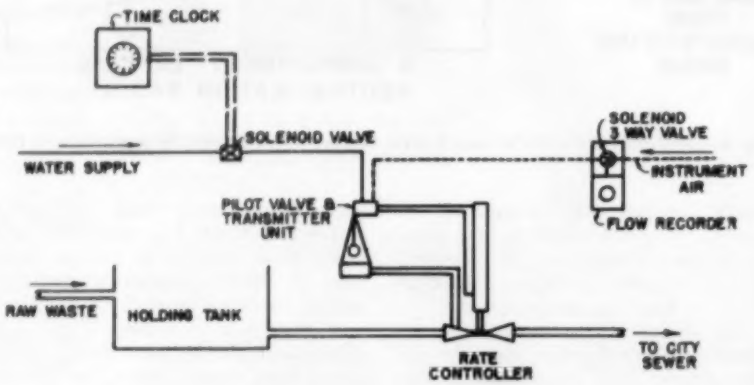

Fig. 4—TIMED discharge of waste to municipal sewer. Assures maximum waste flow during minimum sewage flow.

Problems in Instrumentation

Applications of instrumentation to industrial waste treatment involve many problems which present a challenge both to the sanitary engineer and to the instrument manufacturer.

Primary devices for flow measurement and for determining hydraulic transmission levels very often must handle liquids high in solids; accordingly, consideration must be given to that characteristic and provision must be made for purging. Solids and grease also can plug sample lines, coat or poison electrodes, and weigh down floats. The handling of corrosive liquids and fumes requires suitable choice of resistant materials.

Specific problems are involved in sensitivity of control over a wide range of flow or of pH values. Special consideration must be given to the selection of sampling points, since these are subject to difficulties occasioned by short circuiting through tanks, and by the addition of reagents in dead spots.

The sanitary engineer should be familiar with instrumentation developments, the principles of instrument operation and applications. He should be able to define a given problem to the instrument specialist, basing his specifications on the legal, hydraulic, chemical and biological requirements which apply.

Meters and Instruments in Sewage Works

by GERALD E. RIEPE

Dist. Mgr., B-I-F Industries, Inc., Chicago, Ill.

WHETHER you operate a large and complicated sewage treatment works or a simple primary treatment plant for a small village, it is important to know what your sewage works is doing, and how well or how poorly it is doing the job. It is important to the superintendent or operator; it is important to the city officials; it is important to the citizens and taxpayers; and it is important to local and state health officials. Many reasons may be cited to show why it is important to each of these persons or groups for the operator to know what his plant is doing.

It is not the purpose of this paper to delve into these detailed reasons, except to say that complete knowledge of how a sewage works is operating is important for the sake of the health of the community, for the sake of reducing operating costs and hence taxes, for improving operation, for educating the operator, and for increasing the pride he should have in a job well done. Rather, the purpose of this paper is to discuss ways and means of keeping tab on plant operation and the importance of these means at your disposal.

There are three avenues of approach to knowledge of how a plant is operating. These are: (1) Physical measurement of volumes and weights of sewage and materials handled, as well as of power and energy and dollars expended; (2) Analysis of the composition and concentration of liquids and solids passing through the plant and the determination of the changes therein; and (3) the recording of all of these data with the calculation of operating efficiencies, results, and costs of operation as permanent records of operating accomplishment.

Within a limited space, it is impossible to elaborate fully on all of these three phases.

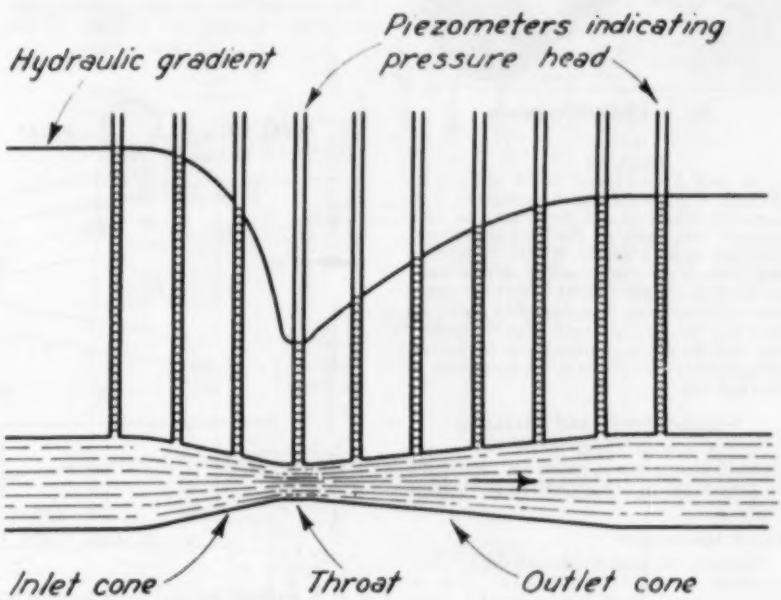

Fig. 2. LOSS OF HEAD curve for typical Venturi tube

*A paper presented at the Rocky Mountain Sewage Works Assn. and released for publication in *Water & Sewage Works*.

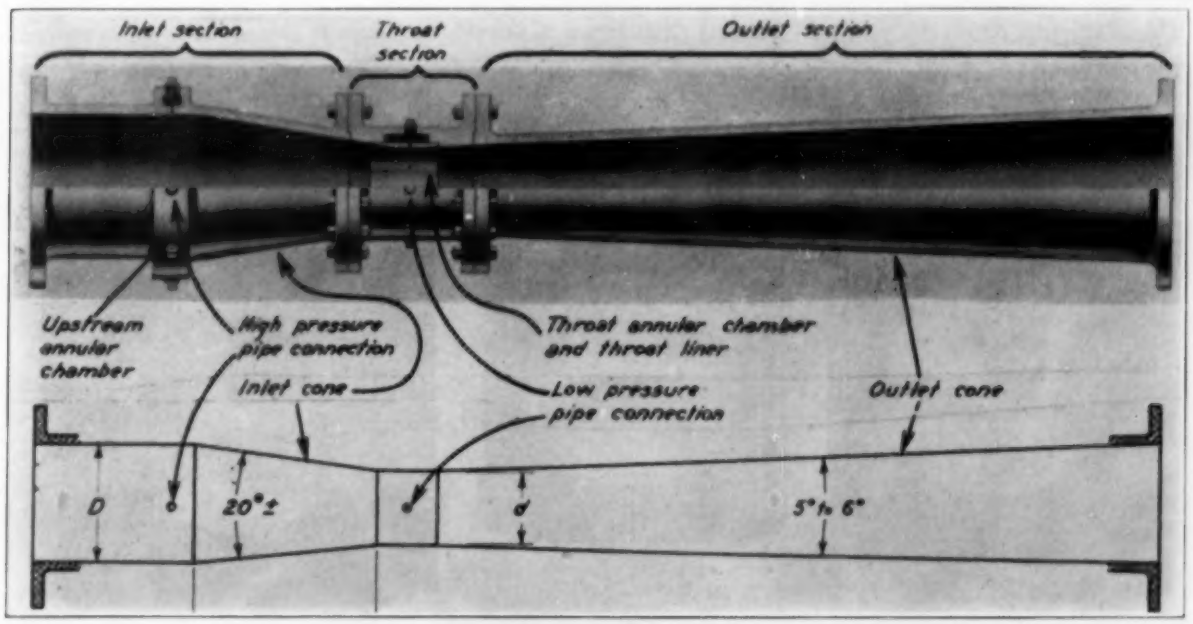

Fig. 1. HERSCHEL standard "long" Venturi meter tube.

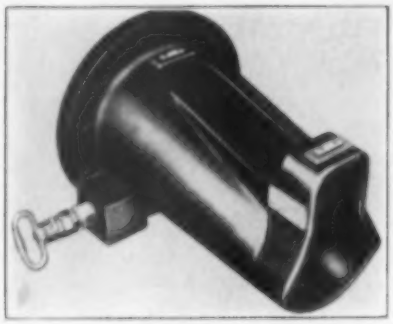

Fig. 3. KENNISON nozzle

It is well known that unless what goes through a plant has been completely and correctly measured, all the tests one may possibly make and all the records one can find time to keep will be of little value. For that reason, it is proposed to devote most of this paper to the subject of measurements and metering, how they should be done and why they are so important. This discussion, too, will be confined principally to normal sewage treatment plants for communities of average size.

Measurements and Metering

In any sewage plant, measurements are made of liquids, solids, gases, and electricity. In general, there are several ways of doing each.

Liquid Measurement

Probably the most important single measurement is that of volume or flow of sewage being treated. It is essential to know continuously, and not to guess, the performance of the whole plant as well as the individual units of treatment. Such knowledge may be assured only if the volume of sewage passing through the plant or through a single unit of treatment is known. It is also essential that the operator know how much, if any, sewage is by-passed during storm flow run-off if the city has combined sewers.

The flow of sewage into a plant may be measured in three ways, by Venturi tube (and meter), by Parshall Flume, and by Kennison Nozzle. The mere use of these devices by themselves is not sufficient. There must, of course, be accompanying gauges and recorders which will be described later. (It is also possible to measure sewage flow by weirs, but this method is infrequently used in sewage treatment plants.)

For the larger sewage works, the Venturi Tube and its instrument are most suitable. The Venturi tube consists of two cones facing in opposite directions and attached to a short throat as shown in Fig. 1. The inlet cone is more steeply shaped and is shorter than the outlet cone.

This device operates on the principle that when the size of the pipe is restricted, the velocity of the liquid passing through it increases and the head (or height the liquid will rise above it) decreases. The difference in the head at the throat and at the inlet is a function of the volume of liquid flowing through. This principle is illustrated in Fig. 2. In addition to the fact that the Venturi Tube offers little or no resistance to the passage of fairly large objects as are often found in sewage, there is also very little head loss through the Venturi Tube, and the readings of a good Venturi Meter will be within one error of ± 2 per cent.

In smaller plants, sewage flow may be measured by the Kennison Nozzle (shown in Fig. 3), which has the additional advan-

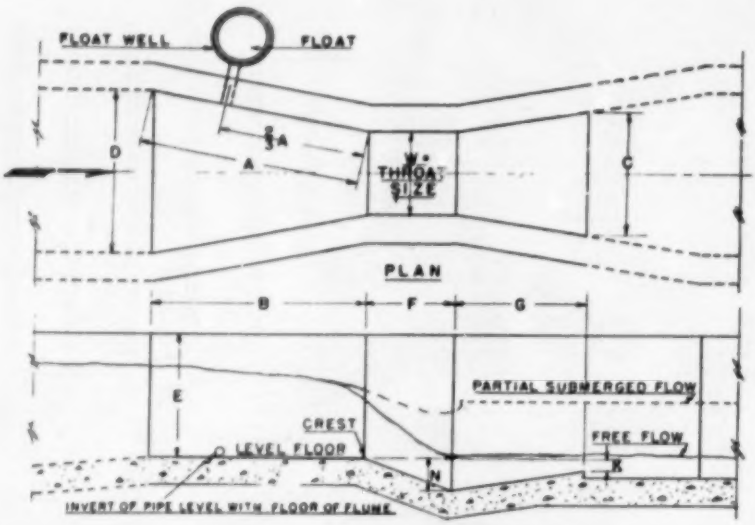

Fig. 4. DIAGRAM of Parshall Flume of "Open Type Venturi"

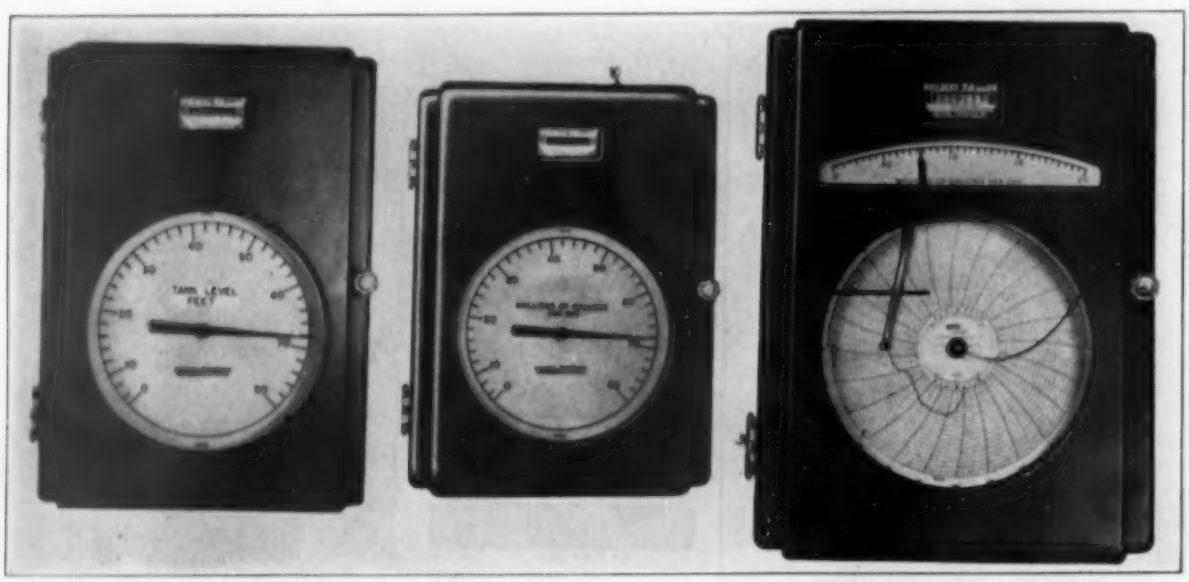

Fig. 5. EXAMPLES OF GAUGES—Liquid level indicator, rate of flow indicator, and totalizer-indicator-recorder

tage of being useful for the purpose of controlling the flow in a grit chamber to the proper velocity desired. It, too, has an exceptional accuracy.

Another primary measuring device used in small sewage works is the Parshall Flume, which is in effect an open Venturi tube as shown in Fig. 4.

All of these measuring units have the advantage that by means of the proper connection with control devices, it is possible to operate many appurtenances in the plant in accordance with the flow of sewage. Such things as chemical feed machines, pumps, chlorinators, air blowers, etc., may be operated in direct ratio to and paced by the metering devices. This "pacing" operation of various units from measuring devices is a fascinating subject in itself, but cannot be covered here.

Recording Devices

Obviously, the mere measurement of any liquid in motion is of little value unless some record of that measurement is made. For that purpose, there are recording instruments which will show at what rate the liquid is flowing. These are the indicating gauges; they only show what is happening at that moment. But the operator wants a record of what has happened, so there is available the indicating-recording type of meter which shows what is happening at the moment as well as recording it on a chart for permanency. A year later an operator can compare the sewage flow as it was then with what it is today.

A more complex, but a more useful recording gauge, is that which not only indicates and records, but also totalizes. This is the totalizing-indicating-recording meter, which will give at the end of 24 hours (or any other period of time) the actual amount of liquid that has passed through a plant or part thereof. These are permanent records (with a high degree of accuracy). They can be used for any purpose, from a simple record of operation to exhibits in a lawsuit, in case one should arise. Examples of these gauges are shown in Fig. 5.

What Liquid Volumes to Measure

What liquids does one measure and where does one make the measurements? Probably no two designing engineers would fully agree on the proper points of location for meters and controllers. However, inasmuch as such devices cost but a fraction of the cost of the whole plant, there is both logic and common sense in "complete metering." In the well-operated plant there is not only the aim to reach and maintain the highest efficiency but also to experiment constantly to lower the cost of operation per unit volume of flow (i.e., per million gallons). Manifestly, it is essential to *know* continuously and *not to guess* the performance of the plant as a whole and its individual units. Thus again it may be said that complete metering is the ideal of good design.

Whether or not complete metering is obtainable may sometimes be dependent on monies available or other circumstances, and it is well to look briefly at the principal points of measurement and what should be measured or metered. Undoubtedly, the most important single measurement is that of the volume of liquid sewage coming into the plant. Therefore, a measuring device (Venturi, Kennison Nozzle, or Parshall Flume) should be placed at the influent to the plant. Circumstances of topography, design, whether or not the sewage must be pumped and other factors dictate the details of location. Measurement may take place before or after grit channels, but where pumping is necessary, the measuring

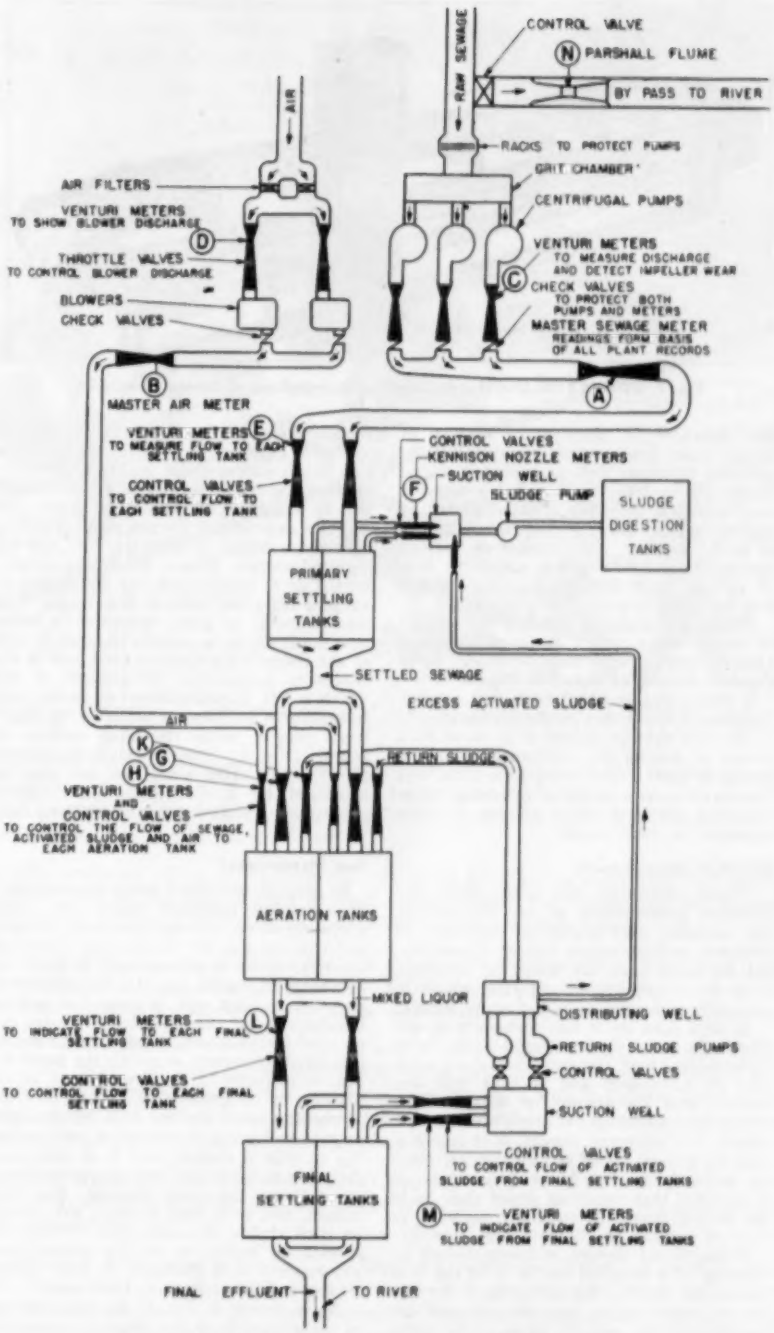
CONTROL VALVE
RAW SEWAGE
N PARSHALL FLUME
BY PASS TO RIVER
RACKS TO PROTECT PUMPS
GRIT CHAMBER
CENTRIFUGAL PUMPS
AIR
AIR FILTERS
VENTURI METERS TO SHOW BLOWER DISCHARGE
D
THROTTLE VALVES TO CONTROL BLOWER DISCHARGE
BLOWERS
CHECK VALVES
VENTURI METERS TO MEASURE DISCHARGE AND DETECT IMPELLER WEAR
C
CHECK VALVES TO PROTECT BOTH PUMPS AND METERS
MASTER SEWAGE METER READINGS FORM BASIS OF ALL PLANT RECORDS
A
B MASTER AIR METER
E VENTURI METERS TO MEASURE FLOW TO EACH SETTLING TANK
CONTROL VALVES TO CONTROL FLOW TO EACH SETTLING TANK
CONTROL VALVES
KENNISON NOZZLE METERS
F SUCTION WELL
SLUDGE PUMP
SLUDGE DIGESTION TANKS
PRIMARY SETTLING TANKS
SETTLED SEWAGE
EXCESS ACTIVATED SLUDGE
AIR
K
G
H VENTURI METERS AND CONTROL VALVES TO CONTROL THE FLOW OF SEWAGE, ACTIVATED SLUDGE AND AIR TO EACH AERATION TANK
RETURN SLUDGE
AERATION TANKS
MIXED LIQUOR
DISTRIBUTING WELL
L VENTURI METERS TO INDICATE FLOW TO EACH FINAL SETTLING TANK
CONTROL VALVES TO CONTROL FLOW TO EACH FINAL SETTLING TANK
RETURN SLUDGE PUMPS
CONTROL VALVES
SUCTION WELL
CONTROL VALVES TO CONTROL FLOW OF ACTIVATED SLUDGE FROM FINAL SETTLING TANKS
FINAL SETTLING TANKS
M VENTURI METERS TO INDICATE FLOW OF ACTIVATED SLUDGE FROM FINAL SETTLING TANKS
FINAL EFFLUENT
TO RIVER

Fig. 6. METER location diagram for activated sludge plant.

device is usually located on the discharge side of the pumps.

For all intents and purposes, the same amount of liquid leaves the plant as enters it, so it is not necessary to measure the effluent of the plant. On the other hand, some of the liquid is removed with the sludge which settles out in a primary treatment plant. Where that sludge is treated or allowed to digest in a separate digestion tank, it is necessary to know how much raw sludge enters those tanks and how much digested sludge leaves the tanks.

If the sludge is pumped, it is best measured by Venturi meters especially designed for the handling of sewage sludge. The Kennison Nozzle can also be used, but the Parshall Flume is not applicable for this purpose. Sometimes sludge volumes into or out of digestion or storage tanks are determined by the rise or fall in liquid level in the tank. For this purpose, level gauges, with indicators and recorders are available. Regardless of ultimate disposal (sand beds, lagoons or incineration), a knowledge of the amount of sludge is highly desirable.

Where secondary treatment is practiced, the volume of sludge obtained and returned to the process should be determined. It is

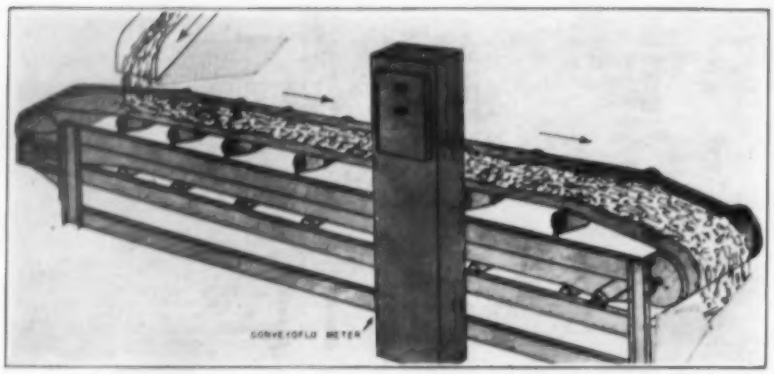

Fig. 7. CONVEYOFLO meter for continuous weighing of sludge filter cake.

also desirable to measure the volume of sludge from final settling tanks following trickling filters as well as activated sludge plants. Perhaps the most complex and the most complete metering is essential for an activated sludge plant. A diagrammatic plan of such, showing the location of various meters, is given in Fig. 6 in which the flow of sewage from influent to final effluent may be easily traced.

Where it is desirable to know the amount of storm water which is by-passed, such measurements may often be made by a Parshall Flume, as shown in Fig. 6.

It might also be added here, that another function of the meters on the discharge side of the raw sewage pumps is to serve as a means of testing the performance of the pumps in their initial acceptance tests, and then to serve as a means of indicating when operating efficiency drops off due to worn impellers or other cause.

Chemical Measurements

Where chemicals are used either for chemical precipitation or for disinfection, the amounts used should of necessity be definitely and accurately known. Chemicals, for the most part, are added as solutions, with the exception of chlorine which is generally measured as a gas or by weight.

In days gone by, it was customary to add chemicals more or less haphazardly, with little control over concentration of the solution or suspension and perhaps still less control over the amount or dosage. Such is not the case today. Where chemicals are added, for whatever reason, it is essential that the amount added and the concentration be definitely known. More importantly, it is essential that chemicals added shall be in the proper dosage to meet any variation in flow of sewage or sludge being treated.

Proportional dosage is accomplished by "pacing" the chemical feeder from the flow measuring device. These chemical feeders are of many styles and designs and are constructed for specific purposes in many instances.

Measurement of Solids

One of the important things to know in a sewage plant is the amount of solids removed from the sewage. Of course, it is possible to actually weigh the amount of grit removed; and if there is continuous grit removal, it is possible to have a continuous weighing record by means of such a device as the Conveyoflo meter. (Fig. 7) Grit is most generally handled in the moist or wet condition in which it comes from the grit channels or grit washers; and to know the amount of dry solids removed, it is necessary to determine the amount of moisture in the grit.

The amount of dry solids removed as sewage sludge is very important. If the raw sludge is digested, it is important to know how much residue there is. Thus, measurement of the liquid volume of sludge in and out is essential and the dry solids are actually determined by analyzing properly collected samples of both the raw and the digested sludge. Where the sludge is elutriated or is conditioned and dewatered by vacuum filtration without elutriation, it is also essential to good operation to know how much sludge is actually handled as well as the chemicals which are used, and if the sludge is incinerated, the amount of ash which is left. Liquid volumes of sludge may be measured by Venturi meter or by liquid level gauges, witth recording meters, of course. (Fig. 5.) Sludge cake from vacuum filtration, or dried sludge or ash may be measured by a Conveyflo meter which operates in connection witth a moving belt. (Fig. 7.)

Gas Measurement

In general, only three gases are measured in a sewage treatment plant,—gas from sluge-digestion, air for activated sludges, and chlorine gas for disinfection. Everyone wants to know how much gas is given off by sludge digestion, and this is particularly true where that gas is used for heating buildings or for the operation of sludge gas or dual-fuel engines. Sludge gas may be measured by meters in which the parts rotate in response to the flow of gas, or by orifices, or by gasometers. All three types of measurement devices may be arranged to give indicating or recording and totalizing records if desired, and it is sometimes desirable to know the rate of gas evolution as well as the total amount. For this reason, too, it is well to have gas meters on each sludge digestion tank. Where gas is used for boilers or for the operation of gas engines, it is advisable to have meters on the individual lines to these units.

As is shown in Fig. 6, air measurement in an activated sludge plant is extremely important to the proper operation of the plant. Meters on air lines, not only show the actual input of air to the aeration units, but also indicate when there is a falling off of the air to the tanks—a condition that might be caused by clogging of the diffuser plates.

Miscellaneous Measurements

In addition to the above information, it is desirable to know how much electricity is used in the plant and it may be desirable to know where that electric power is used. For this purpose, regular type electric meters are used. An operator should also know how much "clean" water is used around his plant, and particularly if that water is purchased from another city department. There are several types of meters available for the measurement of water, depending on the installation, amount of water used, and other factors.

Examples of Meter Installations

Figure 6 is a diagrammatic plan of an activated sludge plant, the various meters used and locations thereof, and is an example of good and complete metering. Perhaps it would be well to describe this layout somewhat in detail.

The two most important Venturi meters are the Master Sewage Meter at A, and the Master Air Meter at B. On these are based the most valuable plant records, but it is apparent that these two meters will not reveal or segregate points or units of poor operating efficiency. This is the duty of additional meters. Operation of the centrifugal pumps is recorded by Venturi meters at C.

Meters located at D show the discharge from each main blower and indicate not only amount of discharge, but by daily record will show any loss in performance. Venturi meters at E can be used to apportion correctly the flow to each of the primary settling tanks.

Sludge from the settling tanks may be removed and measured through Kennison Nozzles at F. The aeration tanks each have three Venturi Meters at G, H, and K. One of these meters measures the influent sewage, the second measures the return sludge, and the third measures the air entering the tank. It is essential to good operation to know how much of each of these materials is entering the aeration tank.

Newly developed gauges, in connection with these Venturi Tubes, are available, not only for indicating and recording rates of flow, but also for showing ratios of sewage and return sludge to incoming sewage. Automatic rate control of any or all of these is possible.

At the two final settling tanks, Venturi Meters at L, with control valves, serve a purpose similar to the Venturi Meters at E, while Venturis at M with control valves make it possible to regulate and record the flow of activated sludge from these tanks to the suction well of the sludge pumps.

As indicated previously, a Parshall Flume, as at N in Fig. 6, is used to measure and record by-passed storm water.

Summary

In brief summary, it may be pointed out that some of this discussion at first glance may not appear to be applicable to the small sewage plant. On the other hand, it should be emphasized, that in small plants as well as large, accurate measurements and recordings of plant operation are doubly important, especially if only daytime attendants are available.

With competent "overseers," such as good meters and recorders, the plant operator has available ready information on flow rates, distribution, ratio values, pump performance, and so forth. These records are available and valuable for seasonal comparison.

In actual dollars, the amount saved by careful and efficient operation of a small plant may not be big—in a large plant it is vital—but when one computes the savings in percentage of the total operating expenses, the value may be surprisingly large —again indicating the importance of good measurements and records. With this in mind, it may well be said "for every dollar invested in metering, that dollar is returned many times over as savings during the life of the plant."

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The female contingent is represented by our oldest in point of service, but still beautiful, Dixie, who guards the treasury and writes the checks. Dixie comes from the South—Suh!—and we caricature her in hoop skirts and the crinoline of the Old South, and a few corkscrew curls, for is not the South supposed to be Democratic?

Next is Seem our machinist, whose first name is Basil, whose education in Russia is equivalent to M.I.T. in this country. His father was "High Brass" in the Russian Imperial Railway System. Basil fought with the White Russians clear across the Siberian Railway to Vladivostok, a fishing boat the hard way to Seattle. He is caricatured with fur, boots and spurs, perhaps Cossack Style, carrying the caliper as Shop Superintendent. He represents our shop service, installation and construction section, as Shop Superintendent.

Next is Mac, the only real full-blooded, true Scotsman. Chief Engineer and Chief Estimator, he with the sharp pencil indicative of his profession, illustrating that oft posed question, "What does a Scotsman wear under his kilt?" The answer—NOTHING.

Next is JRM, the writer, President • Founder • Legally Sole Owner • Sometimes Janitor • who has spent all his life chasing customers. Those diamonds shown on my vest front—if I own them—I don't know where they are. But I have, for over 30 years, been more or less successfully chasing customers, who I sincerely hope have been satisfied, happy and contented that JRM sold them. Supplying "Everything For The Swimming Pool" should make them happy as we explain below.

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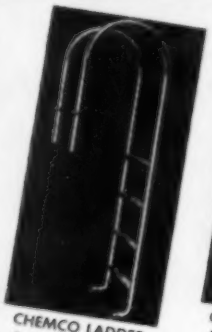

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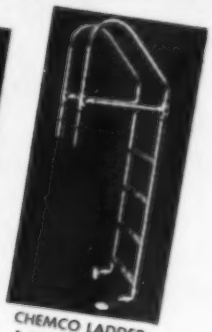

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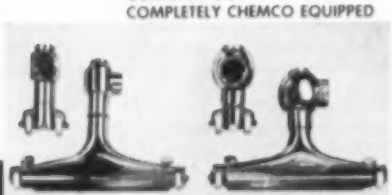

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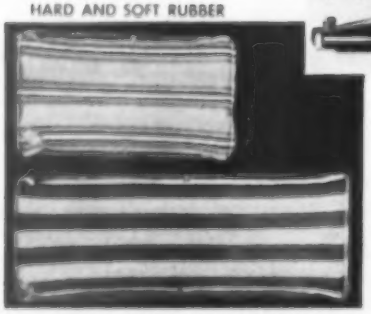

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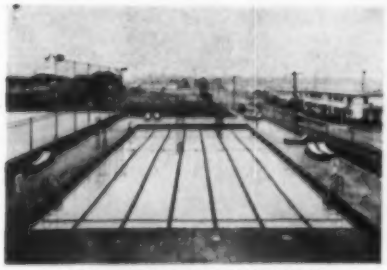

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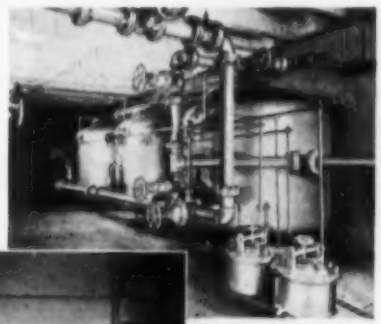

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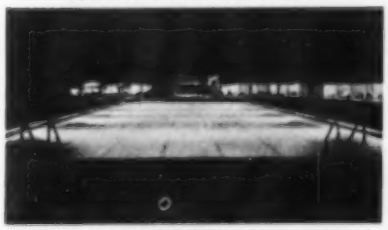

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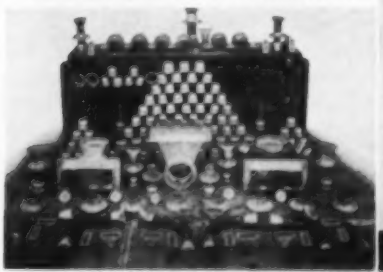

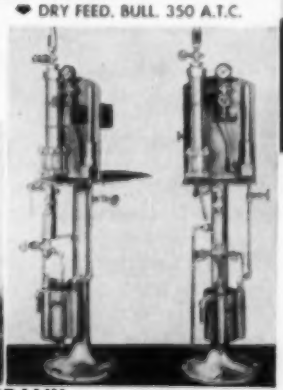

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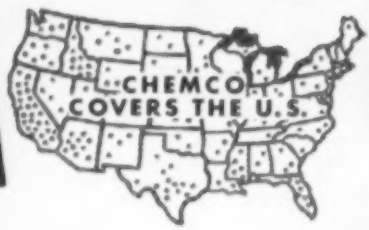

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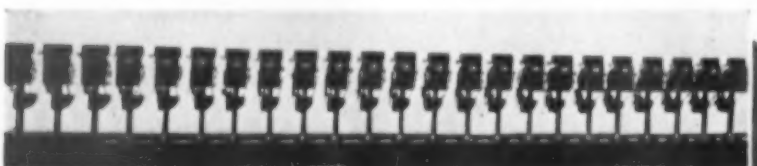

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CHEMICAL HANDLING AND FEEDING

WATER supplies which are not acceptable as is, for domestic consumption must receive treatment. In most cases treatment will involve the use of chemicals of some kind. Chemicals are also used in some types of sewage treatment, too, and in sludge dewatering and in sewage disinfection.

Coagulation of water or sewage may involve the use of aluminum sulfate, sodium aluminate, ferric sulfate, activated silica, and lime depending on the particular process used. Water softening will require lime, soda ash, and carbon dioxide. Disinfection will use chlorine, chlorine dioxide, or ozone. Taste and odor control may utilize activated carbon, chlorine, chlorine dioxide, and copper sulfate.

Sewage sludge conditioning generally uses ferric chlorine and lime but may use other coagulants (ferric sulfate, aluminum chloride, or aluminum sulfate). Industrial wastes may receive chemical treatment of diverse character depending on the waste being treated. Treatment may involve oxidation, reduction, chlorination, neutralization or coagulation, and may utilize other chemicals (sulfur dioxide, sodium meta-bisulfate, barium chloride, sodium sulfate, etc.) in addition to those chemicals mentioned above.

Whenever chemicals are employed in treatment processes, there also will be the problems of handling, storage and feeding.

Handling

Dry chemicals may be shipped in bulk, in paper bags of various sizes, in fibre drums or barrels of different sizes. The kind and size of container used will depend on the bulk density particle size, hygroscopic and chemical characteristics of the particular chemical, and I.C.C. regulations. Choice of container will also depend on the users' facilities for handling and storage.

Bulk chemicals may be unloaded into storage hoppers by air conveyors, tubular conveyors, bucket elevators and screw conveyors. Bags may be transported by hand trucks or on pallets. Drums, and barrels, are handled easily by hand truck.

Chlorine is shipped in 105 and 150 pound cylinders, in ton containers, or in bulk tank cars. Cylinders are handled by hand truck, ton containers by special lifting clamps and chain hoist. Liquid chemicals (i.e., ferric chloride, liquid alum) are shipped in tank truck or tank car.

Storage

Bulk dry chemicals are usually stored in hopper bottomed storage compartments from which they can be transferred to feeding devices. Packaged chemicals whether stored on pallets or not, generally require storage rooms, preferably above the elevation of the chemical feeders. This usually means that elevating equipment is necessary to lift chemicals from ground level to storage room. Storage should be fireproof.

Corrosive liquid chemicals are stored in rubber lined tanks from which they may be discharged to feeders by gravity or by air pressure. Chlorine containers are stored in a cool, dry, well-ventilated place away from heat sources, walkways, elevators, stairways and ventilating system intakes. Indoor storage should be above ground and fireproof outdoor storage should provide protection from direct sun, snow, and debris.

Feeding

The best installation for chemical treatment combines a simple mechanical feeding device, either liquid or dry feeder, with easy chemical handling and simple piping and injection or feeding arrangement. Chlorine is fed by a gas type feeder which dissolves the gas and discharges it as a solution.

Dry chemical feeders have four basic requirements: Accuracy, dosage check, protection against overfeeding, and efficient dissolvers. Dry feeders are of two general types—gravimetric, and volumetric. Gravimetric feeders have an accuracy (or uniformity of feed rate) of ± one per cent, and may be either loss-in-weight feeders or belt type feeders. Volumetric feeders have an accuracy of ± three per cent. The choice of feeder type depends on many factors including accuracy desired.

Solution feeders may be proportioning pumps, Rotodip feeders, or controlled outlet gravity feed. Solution feeders (except the Rotodip feeder) usually have feed rates of less than 57 gal per hr, but have extremely fine dosage control, especially in the proportioning type of diaphragm or constant controlled volume pumps.

Gas (chlorine, sulfur dioxide, or ammonia), is most conveniently fed in special solution type feeders, operating on a vacuum principle. Direct pressure type feeders are available, but are limited in application and not as fool proof and safe as are the vacuum type feeders.

In the selection of chemical feeder equipment it is essential to define operational equipment; determine the storage requirements; and choose the best available location, type of installation and type of feeder.

Materials for Handling

The type of material used for handling chemical solutions depends entirely on the characteristics of the chemical in solution. Corrosive solutions must be handled only in materials that are resistant to that particular solution. Among the materials used are stainless steel, rubber, Duriron, bronze, ceramics, asphalt, hard rubber, plastics, monel, nickel, tantalum, etc. The actual choice of material depends on the chemical involved. A tabulation of chemicals, their characteristics, feeding requirements, and suitable handling materials has been published as Keep Sheet No. 22 by B-I-F Industries, Inc.

Control

The type of control used in chemical feeder operation depends on the chemical being fed, accuracy of feed desired, size of installation, and the variability of feeding requirements.

Manual control equipment is put in operation and shut down, manually, by the operator and the rate of feed in lb per hr or lb per mil gal, is established by manual adjustment. Semi-automatic control or start-stop equipment operates at a rate manually pre-set but in step with pump or timed cycle. Paced proportional feed is accomplished through controls operated from flow measuring devices. Program control equipment provides automatic changing of the chemical feed rate throughout any period to follow changes in required dosage in accordance with a pre-established schedule.

AT EACH of the five Jones Company plants, Chlorine is received in tank cars, repacked in smaller containers selected to meet the customer's needs.

Save storage space and shipping time on your next CHLORINE purchase!

GET FAST DELIVERY ON *MANY* CHLORINE PRODUCTS IN WHATEVER CONTAINER BEST FITS YOUR NEEDS

Stop the cost and nuisance of storing huge amounts of Chlorine. Buy only what you need—whether it's several carloads, just part of one tank car, or as little as 16 lbs.!

You can get less-than-carload shipments of Chlorine from John Wiley Jones. And you get them quickly, because Jones has five distribution centers spotted in important locations around the country, each one ready to make delivery within a matter of hours in many cases.

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You save searching time, too, because you have a *single* convenient and dependable source for *all* your Chlorine products—liquid Chlorine, Calcium Hypochlorite, and Sodium Hypochlorite.

Cylinders, tins, drums, carboys, and ton-tanks—Jones delivers in any type of container you require. This flexibility, plus the speed of Jones' deliveries, gives you complete protection against sudden emergency needs for Chlorine.

Top quality

Jones Chlorine is quality controlled to meet high government standards. Municipalities, public utilities and industrial users have relied on Jones Chlorine for a quarter of a century.

Dependable

We supply more municipalities than all other Chlorine packers combined.

Our trained technical staff will be glad to help you solve *your* Chlorine problem. Take the waste out of your Chlorine buying. Do it now! Write for prices.

LIQUID CHLORINE

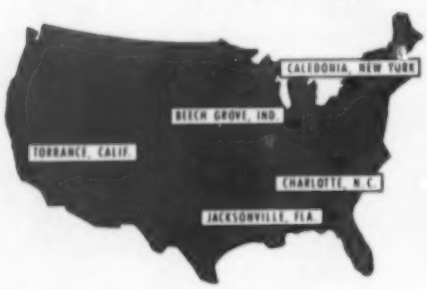
In 16-, 105-, 150-lb. cylinders and 1-ton tanks.

CALCIUM HYPOCHLORITE

(70% available Chlorine) In 3¾- and 5-lb. tins, 100-lb. drums.

SODIUM HYPOCHLORITE

In gallons, carboys. Tankwagon deliveries in 1000-3000 gal. lots



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Recommended Procedures

In the Use of Chlorine at Water and Sewage Plants

From a Report by
The Joint Committee on Chlorine Supply

THE Joint Committee on Chlorine Supply came into being as the outgrowth of abnormal business relations experienced between users and manufacturers of chlorine during World War II and the extraordinary demand for chlorine in the post-war era further amplified by the Korean episode. During this period the chemical industry experienced a phenomenal growth. Demands for chlorine were so great that service suffered, not as to quantity requirements but as to the type of container unit furnished. Many water and sewage plants wanting chlorine in ton containers could not get it. They were obliged to accept and use smaller package units.

It was to investigate this and other related problems that the Federation of Sewage and Industrial Wastes Associations, in October, 1950 set up a special emergency Committee on Chlorine Supply. The objective of this committee was *"to study and investigate problems of chlorine supply and distribution in the water and sewage fields, and to develop recommendations for their solution."* Almost simultaneously a similar committee was established also in the Conference of States Sanitary Engineers. Problems in the water supply field were being adjusted as far as possible through the headquarters office of the American Water Works Assn.

In May 1951 all independent activities in seeking a solution to the chlorine supply problem were combined through the formation of the Joint Committee on Chlorine Supply. Members of the joint committee represented the Conf. of State Sanitary Engineers, and the Federation of Sewage and Industrial Wastes Assns., the Am. Water Works Assn. and the U.S. Public Health Service.

In 1952 the Board of Directors of The Chlorine Institute, Inc., New York, set up a Public Health Advisory Committee, on which the following organizations were requested to appoint representatives: the American Public Health Assn.; the American Water Works Assn.; the Conf. of Municipal Public Health Engrs.; the Conf. of State Sanitary Engrs.; the Federation of Sewage and Industrial Wastes Assns.; the U.S. Public Health Service. Fortunately all members of the Joint Committee were authorized to also represent their organizations on the Public Health Advisory Committee of The Chlorine Institute. Thus a valuable contact with the manufacturers was available and progress of the Joint Committee was thereby facilitated materially through the liaison service of technical committees of the Institute. The responsibility for the report, however, rests entirely with the Joint Committee.

The report has as one of its objectives the standardization of procedures in the use of chlorine in the sanitation field, such as the most practicable or economically feasible size of chlorine container to use; the proper chlorine inventory at users' plants; the schedule of return of chlorine containers, etc. To make such a program work requires its application by and cooperation between consulting engineers, public health engineers, executives and operators of water and sewage plants, and the chlorine manufacturers. The committee is hopeful that the recommendations set forth in the report will receive sufficient support to assure benefits to all concerned.

The Report in Brief

The report is comprised of 11 sections, as follows:

1. Conditions of Use for Chlorine Cylinders and Ton Containers.
2. Chlorine Inventories at Water and Sewage Treatment Plants.
3. Transportation of Liquid Chlorine.
4. Policy and Practices in Return of Empty Containers to Suppliers.
5. Safety in the Use and Handling of Chlorine.
6. Standby Chlorination Equipment.
7. Stationary Bulk Storage of Liquid Chlorine.
8. Procedure for Securing Chlorine in Case of Emergency.
9.* Known Manufacturers of Chlorinators and Solution Feed Units for Hypochlorites.
10.* Liquid Chlorine Producers and Repackagers in the U. S., Canada and Cuba.
11.* Producers of Dry Hypochlorites.

* Information in sections 9, 10 and 11 was furnished by The Chlorine Institute.

The Chlorine Supply Picture

As a matter of information, the capacity for the production of chlorine gas in the United States has increased rapidly. In 1950 production was 2,372,500 tons per year; for 1953 production estimates are 3,467,000 tons of chlorine gas. About 50 per cent of the gas production is liquefied for shipment. Liquid chlorine used for sanitation purposes in 1950 was 73,000 tons; in 1953 estimated use is at 89,000 tons. These figures represent but 6.2 and 5.2% of the total production of liquid chclorine for the years 1950 and 1953. Although sanitation chlorine is a minor production item to the industry, its application in the sanitary field represents one of the most important uses for chlorine—a use of chlorine which must be met irrespective of all exigencies. With this view the Board of Directors of The Chlorine Institute are thoroughly in accord.

It is of vital importance to the public health and welfare that the ever increasing demands for chlorine in the treatment of water and sewage, and in other uses for sanitation purposes, be met. Adjustments in the methods of distribution of the chemical seems to be the greatest current need, looking to an improved relationship between the user and the supplier of chlorine.

Committee Personnel

The Joint Committee on Chlorine Supply consisted of the following members representing the participating organizations listed.

W. J. Scott, (chmn.)	Conf. SSE
R. J. Faust (Secy.)	AWWA
L. H. Enslow	FS & IWA
L. L. Hedgepeth	FS & IWA
H. E. Jordan	AWWA
L. F. Oeming	FS & IWA
B. A. Poole	Conf. SSE
L. F. Warrick	USPHS

Affiliates

F. B. Elder.....APHA

A. H. Herberger.....Conf. MPHE

Important Sections of the Report

Printing of the complete report of the Joint Committee herein is beyond limitations imposed on a publication such as this. The complete document will be printed in the October issues of the AWWA Journal and the Sewage Works Federation's official publication "Sewage and Industrial Wastes". The portions here reproduced are considered the most important to those in charge of water and sewage works.

CONDITIONS OF USE FOR CHLORINE CYLINDERS AND TON CONTAINERS

It is considered that rates of chlorine gas withdrawal should not exceed 40 pounds per 24 hours for a 100 or 150 pound cylinder or 450 pounds per 24 hours for a ton container. It is recognized that for short periods of time these rates may be exceeded by as much as fifty per cent for a period not exceeding 2 hours. With use of an evaporator, liquid chlorine can be drawn from a ton container to an evaporator at a rate much in excess of 450 pounds per 24 hours.

The following adaptation and use of cylinders or ton containers is recommended:

Total Consumption lbs./24 hrs.	Max. Rate of Withdrawal lbs./24 hrs.	Containers Recommended	Remarks
100	100	3 cylinders in use (possibly 6 connected)	Cylinders Only.
100	200	5 cylinders in use (possibly 8 connected)	Cylinders Only.
200	200	5 cylinders in use (possibly 8 connected)	*Ton containers may be justified.
200	300	Ton Containers**	*1 carload provides 5 months storage.
300 or more	300 or more	Ton Containers**	1 carload provides 100 days storage, or less.

*Delivered by truck, since car lot delivery of 15 tons cannot usually be justified.
**Some changes in this schedule may be required for seasonal users of chlorine in order to preclude holding containers over between seasons.

It is assumed that for continuity of operation on most water or sewage works or industrial wastes systems, spare cyinders and spare ton containers would be hooked up. This may mean that a special manifold should be ordered to permit connecting up extra cylinders or ton containers.

CHLORINE INVENTORIES AT WATER AND SEWAGE PLANTS

In the final analysis the chlorine inventory at a user's plant must be predicated solely on the single objective that the treatment must not be stopped because of a lack of chlorine. An ample but practical inventory of chlorine at the user's plants is imperative.

The chlorine inventory needed at a water and sewage treatment plant can be determined by an analysis of the problem. The several factors that have a bearing on the problem are: (1) normal length of time required for delivery from shipping point to the user's plant; (2) the amount of chlorine used per day during periods of high requirements; and finally (3) emergencies which interrupt chlorine deliveries.

In an analysis of the above criteria other factors immediately evolve namely, the definition of inventory terms. By defining terms our understanding of the problem of chlorine inventory is greatly simplified. The terms that need definition are (1) critical inventory; (2) working inventory; and (3) maximum inventory.

Critical Inventory

"Critical Inventory" of chlorine at a water or sewage treatment plant is defined as the number of full unconnected chlorine units equal to the number of units normally connected and in service. Except for systems using less than 5 lbs. per day or for unusual circumstances this type of inventory should not be condoned. With this limited inventory a plant should be considered in emergency operation.

Working Inventory

"Working Inventory" of chlorine at a user's plant may be defined as that inventory which represents a reasonably ample supply to assure continuity of the disinfection treatment. In practice it should approximate (1) a duplication of the connected chlorine units (critical inventory) plus (2) a chlorine reserve equivalent to the length of time required for delivery from the shipping point to the user's plant (varies from 2 to 15 days supply of chlorine depending on local transportation conditions) and plus (3) a chlorine reserve for exigencies, strikes, transportation interruptions, etc. equivalent to a 15 day supply. The "working inventory" for any plant must be developed specifically for that plant, and be based on actual conditions.

Maximum Inventory

"Maximum Inventory" is defined as that inventory which is equivalent to a 60 day supply of chlorine at the user's plant at normal rates of use. The small users of chlorine (5 lbs/day or less) must be excepted from this definition. Beyond the small plant there are few if any practical reasons to exceed the 60 day inventory. To do so ties up an unwarranted stock of cylinders and containers. Maximum inventories should be considered as being temporary only.

Recommendations

Regular chlorine shipping schedules, or the placing of orders for chlorine, should be developed or timed to maintain the chlorine inventories at the user's plants at approximately the "working inventory" as defined above. In practice this objective may be difficult to attain due to the size of chlorine deliveries, particularly where shipments are represented by car-load lots. Thus working inventories will vary in size. However, the extremes of these variations should be restricted between the critical and the maximum inventories. To maintain such a reasonable and well defined inventory should prove advantageous to user and manufacturer alike.

Based on the foregoing definitions the accompanying table reduces to practical terms the critical, the working and the maximum chlorine inventories for plants using chlorine at the rates of 0.5 to 2000 lbs. per day.

TRANSPORTATION OF LIQUID CHLORINE

Chlorine is shipped as a compressed liquefied gas in cylinders, ton containers and single unit tank cars. These three styles of containers are designed and built to the regulations and specifications of the Interstate Commerce Commission under a penal statute—(62 Stat. 738).

The sizes of these styles of containers are as follows:

Cylinders

Cylinder capacities range from 1 lb. to 150 lbs. of chlorine, but the 150 lbs. size is most-frequently used. Cylinders (usually known officially as ICC-3A480) may be shipped by motor and rail carriers in any quantity, subject only to weight limitations.

A minimum truckload lot weighs

MATHIESON QUALITY PRODUCTS FOR TREATMENT OF WATER AND WASTES

TREATMENT OF RAW WATER • CLARIFICATION OF TURBID AND COLORED SUPPLIES • REMOVAL OF TASTES AND ODORS • WATER SOFTENING • STERILIZING NEW EQUIPMENT • CLEANING SUPPLY EQUIPMENT AND INSTALLATIONS • EMERGENCY CHLORINATION

HTH GRANULAR

The following outstanding properties of HTH have gained wide acceptance for the product by water works operators and others using HTH in water treatment: Dependable strength of over 70% available chlorine, high stability that maintains the product at full strength even after months of storage at summer temperatures, low calcium chloride content that eliminates hygroscopic tendencies, rapid and complete solubility of the active element in water.

The available chlorine in HTH is in the form of true calcium hypochlorite, the formula of which is $Ca(OCl)_2$. When consideration is given to the light-weight, non-returnable containers in which HTH is shipped, its available chlorine per pound of gross weight exceeds that of liquid chlorine in the 100- and 150-lb. cylinders. Moreover, its use involves none of the hazards that attend the handling and use of liquid chlorine. It is little wonder, therefore, that water works men avail themselves of this convenient, safe source of available chlorine wherever practicable.

The 5-lb. cans of HTH Granular, packed 9 to the case, are particularly convenient for sanitization of newly laid pipelines, isolated water supplies and at locations where transportation of the chlorine carrier is a troublesome factor. For continuous or emergency hypochlorination of water supplies, the 100-lb. drum of HTH Granular may be a more economical unit. In determining the more desirable package, however, consideration should be given to the advantage of keeping a product not immediately needed in sealed 5-lb. cans rather than in a 100-lb. drum that is frequently opened.

HTH TABLETS

For convenient handling in many water treatment applications, HTH is also available as HTH Tablets. This product is simply HTH in the form of compressed, easy-to-handle tablets which dissolve slowly and provide a continuous source of available chlorine over an extended period of time.

HTH Tablets are made wholly of dependable HTH and contain 70% available chlorine the same as the time-tested granular product, HTH Granular. The tablets are stable and dust-free and have an unusually high degree of strength. HTH Tablets thus offer an exceptionally safe and convenient means of handling, measuring and storing available chlorine. HTH Tablets are packed in 100-lb. drums and in cases of six 7½-lb. cans.

HTH TABLET HYPOCHLORINATOR

By use of the HTH Tablet Hypochlorinator the convenience offered by the HTH in tablet form can be combined with accurate metering and feeding of hypochlorite solutions. This equipment, specifically designed by the Mathieson technical staff to dissolve HTH Tablets and to dispense the resultant hypochlorite solutions, provides a convenient and efficient method of feeding available chlorine at rates which can be accurately controlled and quickly varied to cover a wide range of operating demands.

The HTH Tablet Hypochlorinator is of practical design, compact construction, and attractive appearance; it is easy to install and very simple to operate. Moreover, HTH Tablet chlorination eliminates all measuring and weighing operations, and requires no preparation of stock solutions. The HTH Tablet Hypochlorinator is engineered to give long-time reliable service. Initial cost is low, and since the unit operates with no moving parts, maintenance and upkeep requirements are almost negligible.

HTH Tablets and the HTH Tablet Hypochlorinator can be applied successfully and economically in many cases where line or flow chlorination is desired. Such uses include chlorination of industrial wastes, industrial sewage, potable water, ponds, swimming pools and spray towers, and the feeding of hypochlorite solutions in dairies, canneries, bottling plants and other food and beverage plants.

SODIUM CHLORITE

Chlorine dioxide (ClO_2), is produced at the point of use by the interaction of chlorine and sodium chlorite ($NaClO_2$). The reaction takes place in a simple mixing chamber or solution generator, and the reagents may be (1) solutions of chlorine and sodium chlorite or (2) solutions of HTH, acid and sodium chlorite. The dilute chlorine dioxide solution thus formed is fed directly into the water for taste and odor control and for disinfection.

Mathieson Sodium Chlorite Technical is a dry, straw-colored, crystalline material containing 130 per cent available chlorine. It is non-hygroscopic, extremely soluble in water and very stable both in dry form and in solution. Packed in 100-lb. drums and 25-lb. pails.

SULPHATE OF ALUMINA
Activated Alum Brand

Activated Alum—the only alum designed exclusively for use in the field of water and sewage treatment—contains finely ground natural silicates, providing a free-flowing, less hygroscopic product of porous structure and higher alumina content. Activated Alum is used and preferred by several of the largest municipal water works in the U. S. A. Packed in 100-lb. six-ply paper bags.

PH-PLUS (Fused Alkali)

A special moisture-free alkali for water treatment, fused at 1,800° F. and cast in ½-lb. conical cakes. The cakes have a purity and rate of solution particularly desirable for pH control of swimming pool water and general industrial water treatment. Shipped in 100-lb. bags.

Other Mathieson Chemicals for Water Treatment:

Soda Ash • Caustic Soda • Liquid Chlorine

Ammonia • Hydrazine • Sulphuric Acid

For complete information and detailed technical data see your Olin Mathieson representative or write—

OLIN MATHIESON CHEMICAL CORPORATION
Industrial Chemicals Division
Baltimore 3, Maryland

MATHIESON

RECOMMENDED CHLORINE INVENTORIES AT WATER AND SEWAGE PLANTS

Chlorine Used per Day (Pounds Avg.)	Critical Inventory (a) (None of which is in use)	Working Inventory (None of which is in use)	Maximum Inventory (None of which is in use)
0.5	1—150 lb. cylinders	1—150 lb. cylinders	2—150 lb. cylinders
2.0	1—150 lb. "	1—150 lb. "	2—150 lb. "
5.0	1—150 lb. "	1—150 lb. "	3—150 lb. "
10.0	1—150 lb. "	3—150 lb. "	4—150 lb. " (c)
20.0	1—150 lb. "	4–5—150 lb. " (b)	8—150 lb. " (c)
50.0	2–3—150 lb. "	8–12—150 lb. " (b)	20—150 lb. " (c)
100.0	3–5—150 lb. "	16–24—150 lb. " (b)	40—150 lb. " (c)
200.0	6–8—150 lb. "	30–47—150 lb. " (b)	80—150 lb. " (c)
400.0	1—ton container	4–6—ton container (b)	9—ton containers (c) (d)
500.0	2— " "	8–10— " " (b)	15— " " (c) (d)
1000.0	2–4— " "	12–18— " " (b)	30— " " (c)
2000.0	4–6— " "	22–35— " " (b)	60— " " (c)

Note:—100 lb. cylinders are available. Where they are used instead of the 150 lb. cylinders the net weight of chlorine in inventory should substantially agree with that shown in the table.

(a)—The recommended "Critical Inventory" column also represents the number of cylinders or containers usually in active service. Local conditions could affect these figures materially. Irrespective of the number of units in service the principle as expressed in the definition of "Critical Inventory" should still apply.

(b)—The smaller of the two numbers represents the "working inventory" where deliveries require 2 days. The larger figure represents the "Working Inventory" where deliveries take 15 days.

(c)—These figures roughly represent 60 days of chlorine inventory.

(d)—Maximum inventories for these categories are for plants receiving chlorine delivery by truck. For plants receiving chlorine delivery by railroading car (15-one-ton containers) the "Maximum Inventories" should be not more than 19 and 23 ton containers, respectively, for plants using 300 and 500 lbs. per day. Users of 1 ton or more of chlorine per day should consider the use of single unit tank cars.

23,000 lbs. gross or 20,000 lbs. gross in certain parts of the country depending on truck tariffs. A 23,000 lb. truckload constitutes approximately 86 cylinders of 150 lbs. net each.

A minimum carload lot of cylinders weighs 30,000 lbs. gross throughout the United States and constitutes approximately 110 cylinders of 150 lbs. net each.

The cylinder shells vary somewhat in weight so scales should be adjusted accordingly for each cylinder being used. The approximate tare weights of 100 and 150 pound cylinders follow:

Cylinder Contents (Lbs. Net)	Approx. Tare Wgt. (Pounds) Lgt. Type	Hvy. Type
100	73	85
150	92	125

Ton Containers and TMU Tank Cars

The ton container holding 1 ton of chlorine may be shipped in any quantity on motor trucks or semi-trailers subject to weight limitations, and the empty ton containers may likewise be returned. What is known as the Multiple Unit Tank Car (officially known as TMU), holding 15 ton containers on an especially designed underframe similar to a flat car with tanks (containers) cradled and anchored, may be shipped to a siding owned by the consignee or leased from the rail carrier by the consignee. This TMU tank car may, under certain regulations of the Interstate Commerce Commission, be shipped to a nearby rail carrier track, the ton containers both loaded and empty being handled by the consignee. Rail carrier transportation of loaded ton containers, except on TMU tank cars, is prohibited. In the rail carrier transportation of TMU loaded tank cars, the weight for tariff purposes is the *weight of the chlorine only*. In the rail transportation of empty ton containers, the TMU underframe must have all 15 empty ton containers in place. As an alternative, *empty* ton containers may be returned in any number by ordinary rail transportation or by motor carrier. Freight rates via motor carriers apply on *the gross weight* of the loaded ton containers, except where minimum quantity rates are in effect. In such case that minimum must be shipped. Special equipment is required for handling ton containers whether delivered by truck or by rail. Stationary or movable cranes or travelling overhead rail hoists are necessary along with some type of lifting rig.

Single Unit Tank Cars

These tank cars are in three sizes holding 16 tons chlorine, 30 tons chlorine, 55 tons chlorine respectively. All three sizes are in use in sanitation, the two smaller sizes being most in use. A single unit tank car must be consigned to and unloaded on a private or leased rail siding. The unloading of single unit tank cars requires skill and should never be undertaken by other than trained personnel.

RETURN OF EMPTY CONTAINERS POLICY AND PRACTICES

Liquid chlorine shipping containers represent sizeable funds invested by the manufacturers or suppliers of liquid chlorine. The interest on the total invested funds in 150 lb. chlorine cylinders or ton containers, plus depreciation on containers and valves, must be included in the factory-door cost of producing and packaging liquid chlorine. Furthermore, when governmental restrictions on the uses of steel are in force it is difficult for chlorine producers and/or suppliers to procure additional containers.

It should be clear, taking into account the above circumstances, that the larger the stock of containers a chlorine producer is required to own and maintain, the greater the factory-door cost of the packaged chlorine. Any group of chlorine purchasers which creates the necessity of producers maintaining a larger inventory of chlorine containers comprises the least attractice (profitable) class of purchasers of chlorine. More importantly, that group of chlorine purchasers which does not promptly return empty containers may well create a more consequential problem —namely, that of an insufficient number of containers on hand for the producer to completely fill orders in a single shipment. This creates confusion at both ends and adds to the producer's cost of supplying the chlorine user through splitting of shipments, extra bookkeeping, billing, etc. At the producers' end it likewise adds to costs of handling, record keeping, etc. At the same time, the chlorine user who neglects to return empty containers as promptly as is permissible is not showing consideration either for the supplier or other chlorine customers who may suffer the consequences of recurring shortages of containers in the hands of the supplier.

During World War II the matter of empty containers in the hands of those responsible for operation of water and sewage plants became a problem of marked consequence. The pleas for more prompt return of empty containers, in smaller shipments than customarily practiced, bore fruit and relieved a growingly serious situation. It behooves all users of liquid

chlorine to reinstate the practice of prompt return of empty cylinders at regular intervals, regardless of the number available for return. When considering the number of water and sewage plants using chlorine, and multiplying this number by even a minor average number of returned cylinders per plant each month the boost in the rate of cylinder turnover will constitute an impressive accomplishment.

Considerations for Seasonal Users of Chlorine

In instances wrere chlorination is provided on a seasonable basis, such as sewage effluent chlorination during the bathing season or for the seasonal protection of shellfish areas, sewage chlorination for summer odor control etc., the tying up of chlorine containers may be particularly objectionable should the chlorination season end with a sizeable number of full chlorine containers on hand. In this instance the municipality has a dead investment in chlorine to be carried through the non-use months. This is particularly undesirable where the chlorine is being supplied in one ton containers.

Chlorine users in the seasonal category can do much to improve the container turnover picture if they will look ahead a bit and place their final order of the season at a time, and in a quantity, that will reduce the number of carry-over full containers to a minimum. Possibly whatever remains at the close of the chlorination season can be transferred to the local water department or, if need be, sold to an adjoining community.

Where one ton containers are involved the user may find it expedient to procure chlorine in ton containers for transportation by truck, to finish out the chlorination season, rather than order another 15 unit car and tie-up a number of these expensive containers during the non-chlorinating months. Second best would be the purchase of a less than car load shipment of chlorine in 150 lb. cylinders to finish out the season. In the case of the larger plants the adoption of bulk-storage of chlorine, as hereinafter discussed, may prove to be the most effective solution.

There may be other methods of providing a more rapid rate of chlorine container turnover in given situations than have been suggested herein. The whole point of this discussion is an attempt to prevail upon plant operators to practice the "golden rule" in the matter of keeping chlorine containers in mobile circulation for the benefit of all concerned.

STATIONARY BULK-STORAGE OF LIQUID CHLORINE*

Stationary bulk-storage of liquid chlorine is practical for large water and sewage plants under these conditions: (a) The storage tanks are of proper (approved) construction for chlorine service, (b) the storage tanks are mounted so that the contents may be weighed at any time; (c) the tanks are well and properly maintained, (d) the quantity stored therein does not exceed safe loading limits, and (e) the loading and unloading practices are safe.

Hazards

The potential hazards of such storage are substantially the same as those of the storage of liquid chlorine in tank cars on water and sewage plant premises, differing only in that (a) unskilled maintenance of the storage tank may result in escape of chlorine, (b) over-filling of the tank may cause hydrostatic rupture of the tank and the complete discharge of its loading to the surrounding air, and (c) in the event of fire, it will not be possible to move the stationary tank to a safer location.

Tank Construction

A specification for stationary bulk chlorine storage installations is being prepared by a technical committee of The Chlorine Institute, Inc. Reference should be made to the specification when it becomes available.

*Ed. Note: For more complete information, suggestions and recommendations pertaining to the practibility of "Bulk-Storage of Liquid Chlorine" see the following articles. "Stationary Bulk-Storage of Liquid Chlorine" by A. S. Woodward and L. L. Hedgepeth.—*W. & S. W.*, August 1953. "Bulk-Storage of Liquid Chlorine at San Francisco Sewage Plants" by Ben. Benas, *W. & S. W.*, October 1953.

SECURING CHLORINE IN CASE OF AN EMERGENCY OR CHLORINE SHORTAGE

The procedure to be followed to secure chlorine in the case of an emergency will necessarily be dependent on the general type of emergency which occurs. For the purpose of suggesting a routine procedure to be followed, emergencies have been separated into two types or categories and a procedure applicable to each is suggested.

1. Difficulty in obtaining needed normal chlorine requirements from suppliers.

The user should make every reasonable effort to obtain chlorine through ordinary channels. Three or more suppliers should be contacted and requested to supply the requirements. In the event that there is advertisement for bids and no bids are received an inquiry as to why they have not submitted a bid should be made of the supplier or suppliers which have been filling the more recent orders.

If the above efforts fail to obtain the necessary supply of chlorine, a request for assistance should be directed to the State Department of Health. In turn the Department of Health should if necessary, communicate the needs to the Surgeon General of the U. S. Public Health Service, Washington, D.C. with a request for assistance. Information accompanying this request should include:

a: Purpose for which chlorine is used.
b: Quantity used in the past year.
c: Estimated requirements during the next 12 months.
d: Quantity which it is desired to purchase immediately.
e: The name of the firm or firms which have filled the more recent orders for chlorine.
f: A fair description of the efforts made to purchase chlorine, including the name of the firms which have refused to accept orders and their reported reasons for not accepting or filling orders.

2. A catastrophe or emergency which results in immediate need of much larger quantities of chlorine than are on hand or immediately available.

Prior planning and preparation is essential to efficiently cope with an emergency which requires greater quantities of chlorine than are normally available. As a general rule the executives of the local utilities or installations which are large sanitation users of chlorine, such as water and sewage treatment plants, will be a part of the local Office of Civilian Defense organization. The responsibilities of these executives to provide safe water and waste treatment during an emergency will include the responsibility of obtaining needed quantities of chlorine.

Local agencies should initiate and carry out the necessary planning to assure that needed chlorine can be obtained. The following are believed to be essential components of such planning by the utilities.

a: An estimate should be made of the possible situations or conditions requiring the use of appreciable amounts of chlorine and the maximum quantity that may be needed.

b: A list of nearby stocks of chlorine should be developed. This list should include all organizations which usually maintain a stock of chlorine on hand such as chlorine suppliers and repackagers, industrial users of chlorine, water plants, sewage plants, swimming pools, etc. The list should contain the following information with respect to each of the above stocks. (1) Chlorine or chlorine compounds available; (2) Size of containers; (3) Quantity normally on hand which could be available for use in emergency.

c: In addition to chlorine supply equivalent information relative to chlorinating equipment which might be available for use in any emergency should be obtained. Swimming pools might be a particularly good source of the smaller sizes of chlorinating equipment as frequently the pools may be inoperative or could be closed in an emergency.

(The full report carries complete lists of all known producers and re-packagers of liquid chlorine and hypochlorites in the U. S. and Canada.)

In the event an emergency occurs the following general procedure should be as follows:

(1) The local and State Health Departments should be immediately informed and requested to supply as much needed assistance as possible.

(2) The supplies of chlorine and chlorinating equipment sufficient for the immediate needs should be obtained from sources previously listed which can spare them at that particular time.

(3) As soon as the immediate exigencies of the situation have been met and estimates can be made of the chlorine requirements for the duration of the emergency or for a reasonable portion of the period which it is expected to exist, orders should be placed with regular suppliers. These orders should be for the amounts required in excess of the quantities loaned or obtained from other stocks plus that necessary to replace that loaned, unless other arrangements have previously been made for replacement.

STANDBY EQUIPMENT FOR CHLORINATION

The use of chlorination equipment in water, sewage and related fields may be dictated for various reasons. These would include, among others, protection of the public health from transmission of pathogenic microorganisms, prevention of unpleasant odors, reduction of oxygen-consuming potential, reduction of gross bacterial populations and chemical stabilization of certain products. The following recommendations concerning the provision of standby equipment relate only to that use of chlorination in which the protection of the public health is the reason for chlorination.

Standby equipment should be available in any installation where chlorination is practiced for the protection of public health and welfare. This applies not only to water treatment plants (at which chlorination would be used for the protection of public health), but also to those sewage and industrial waste treatment installations where chlorination of the effluent is demanded. Chlorination as used in sewage treatment for the protection of the health of the public might be directed toward the protection of a public water supply, of shellfish culture areas, and of bathing beaches.

In the small plant, whether it be water supply, sewage disposal or industrial waste treatment, requiring only one chlorinator for normal operation, one additional chlorinator should be provided as a stand-by and for emergency situations. The size of the emergency unit should equal in capacity that of the basically required unit. In installations requiring two or more chlorinating units in operation, stand-by needs should be met by providing a duplicate of the largest unit of the group to provide one more unit than is required for normal maximum demand. Consideration should be given in the original design to the desirability of using several small units providing flexibility not available with one or two large units.

Several general comments are made with regard to stand-by equipment. Of equal importance to provision of stand-by equipment is the regular frequent servicing of all chlorinating equipment. Any stand-by equipment should be kept in perfect running order at all times. Borrowing of parts from stand-by equipment should not be permitted. A definite schedule of chlorinator use should include frequent routine operation of any stand-by equipment. Reliance on emergency equipment maintained by state health departments should not be considered as serving in lieu of stand-by equipment located at the installation itself. Possible availability of equipment from manufacturers should not be considered as meeting stand-by equipment needs. Knowledge of types of equipment used in nearby plants might prove of limited service at times when it might be possible to borrow a part of a chlorinating unit to replace a damaged or broken part.

Considering power, many chlorine feeders employed in the treatment of water supplies, sewage or industrial wastes are dependent on power to operate pumps or provide auxiliary water or air pressure used in connection with the feeders. Where there is also need for power to produce the flow of water, sewage or industrial wastes that are to be treated, the power for the chlorine feeder may be derived from the same source; an interruption of the flow is timed with the interruption of the chlorination. However, where the flow of liquid to be treated is by gravity or where the source of power to produce the flow is from some other source than the source used to operate the chlorinator, failure of the electric power or other power used to operate a chlorinator may cause interruption of the chlorinee disinfection of the flow. A common practice is to install hydraulic pumps along with electric power to operate chlorinators, with the hydraulic pumps cutting in automatically when electric power is interrupted.

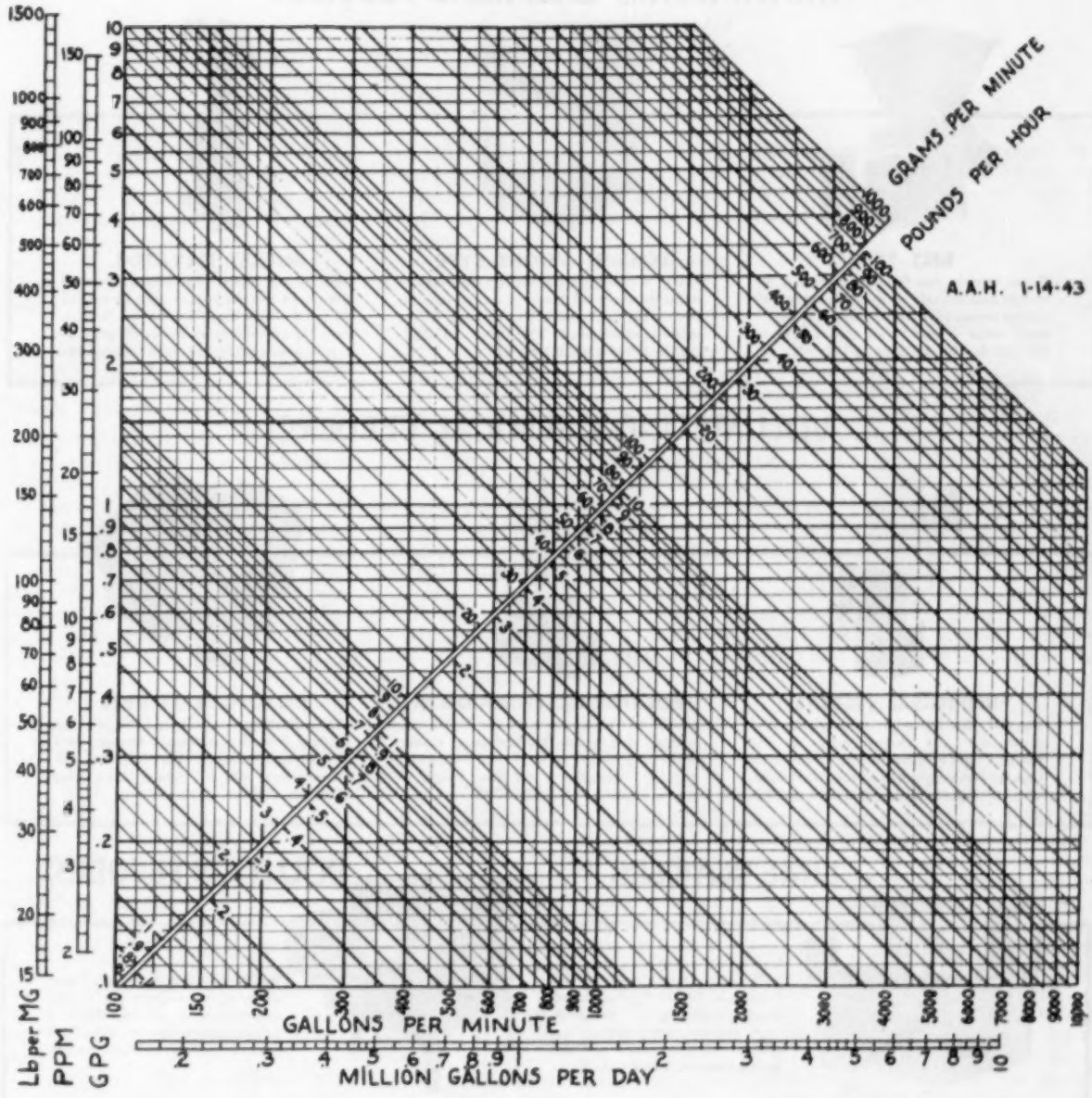
In the air-operated chlorinators, air is usually provided by small, electrically operated compressors. Interruption of the flow of compressed air through power failure will shut down the chlorinators. To prevent such interruption of chlorination, an auxiliary source of compressed air is required. This may be provided by a gasoline engine driven auxiliary compressor or by a reserve supply of cylinders of inert gas such as carbon dioxide. A minimum of two cylinders of carbon dioxide in service at the same time on each chlorinator is required to operate one chlorinator for a minimum of 10 hours. The use of high pressure carbon dioxide presents an operational hazard. Such an installation should be made and operated only in accordance with the recommendations of the chlorinator manufacturer.

Safe Practices in Handling Chlorine

The section of the Report of the Joint Committee which discusses "Safety in the Handling and Use of Chlorine" is separately published in SECTION III of this 1955 R&D under the title "Safe Practices in Chlorine Handling".

Checking Chart
For Dry Chemical Feed Machines

By A. A. HIRSCH
State Department of Education, Baton Rouge, Louisiana



The chart shown herewith offers a convenient means to check on the delivery of dry feed machines when the pumpage rate and the desired dosage is known. Rate of feed is expressed in grams per minute to enable weighing a timed discharge to check the feeder setting, and in pounds per hour to figure quickly the quantity needed in the hopper for each expected hour of operation. Chlorine dosage may be read knowing the change in platform scale readings per hour and the flow.

Parallel scales along each axis allow rapid conversion from one system of expression to another. On the vertical axis grains per gallon, parts per million and pounds per million gallons are quickly related by scanning directly across the scales. Gallons per minute and million gallons per day are similarly converted along the horizontal scale. In the plot grams per minute and pounds per hour are interchangeable across the diagonal scales. Pounds per hour is more logical from an operator's viewpoint than pounds per day. Many small plants operate only part of a day, or have a limited number of pumping steps, in which case pounds per day is merely a bookkeeping quantity.

A wide range in coverage is provided by the logarithmic divisions. High values not included on the chart may be read by using a tenth or hundredth of the quantity and applying the corresponding multiplier to the reading.

Example. How many grams per minute must be discharged from a dry feeder to give a 2 grain per gallon dosage while operating a 300 gallon per minute system?

Solution. Find the point where the 2 grain per gallon line and the 300 gallon per minute vertical intersect. This point lies between the 35 and 40 gram per minute diagonals at about 38 grams per minute. By projecting this value across the diagonal scales the hourly chemical consumption of 5.0 pounds is read.

When the answer falls in the area occupied by pounds per hour diagonals readings are converted to grams per minute by projecting in the same manner across the oblique scale.

When a metric scale is unavailable grams per minute may be obtained directly by catching the dry feeder discharge for 170 seconds and multiplying the weight in ounces by 10.

OMEGA

You can depend on Omega for "the last word in feeders" . . . and the answer to your chemical feeding problem . . . *always!*

GRAVIMETRIC CHEMICAL FEEDERS

BELT TYPE

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Handles dry material dependably and accurately . . . whether lumps or fine powder, light or heavy. Large throat openings, effective agitation at the outlet zone. 40 to 1 range. Furnished in 3 sizes. Bulletin 20.20.

VOLUMETRIC FLUORIDIZER

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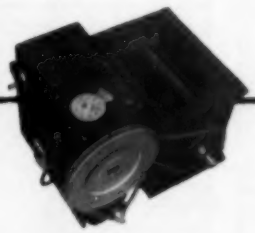

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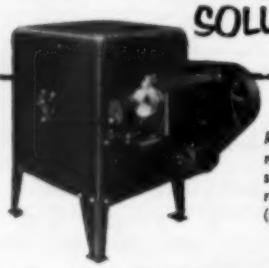

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Write for Bulletins on individual products, or comprehensive Bulletin B-I-F 3 . . . also Bulletin 10-K12 "Chemicals Used in Water & Sewage Treatment".
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B-I-F METERS FEEDERS CONTROLS

Chemical Feeder Puzzlers

"Believe-it-or-not" experiences with chemical feeder operation

by R. J. LEVEQUE

Sales Manager, Omega Machine Co., Providence, R. I.

TRUTH is stranger than fiction, and a number of unusual experiences with regard to chemical feeders seems to emphasize the validity of the statement. If these occurrences had not happened at installations of Omega Machine Co. chemical feeders, I wouldn't have believed them, myself. I can however, vouch for the authenticity of these experiences from my own files.

Where Does The Air Go?

In a rather large metropolitan city, a Loss-In-Weight type Gravimetric Feeder had been installed underneath a large storage bin. The feeder hopper was filled periodically by opening a bin gate between the overhead storage bin and the feeder hopper. For this arrangement, a 4-in. diam. vent is placed on top of the feeder hopper so that the displaced air can be exhausted. Our drawings showed a 4-in. duct connected to this sleeve and run up through the floor above into the storage bin. This connection was to be made by the purchaser. The floor above, however, happened to be very thick with considerable reinforcing steel in it.

The utility's maintenance crew, in making the installation, apparently thought there was an easier way to vent the feeder hopper. They installed an elbow on the sleeve and ran the exhaust duct down into the feeder dissolving chamber on the assumption that this would be a good way to get rid of the dust by exhausting it down into the water in the dissolving chamber.

Soon after the installation was made, there seemed to be considerable splashing of water in the dissolving chamber and an unsightly caking of the chemical on the interior of the feeder housing. In this case, a thoroughly competent maintenance crew overlooked the fact that displaced air in the hopper would seek the highest point in which to exhaust itself.

Our serviceman took one look at that elbow and surmised that air collecting at that point was building up a pressure which, when it became great enough, exploded and blew downward with enough force to cause splashing of the water. In order to avoid a long extension of dust duct up through the thick and heavily reinforced floor, the elbow was removed and to the duct was attached a spring-suspended, cloth, filter bag as used in dust collector units. Thereafter when the feeder hopper was filled from the storage bin, the displaced air and dust blew straight upward into the bag. The air filtered out through the bag while the dust was retained and dropped back down into the hopper when the loading procedure was finished.

More Air

Another "air" experience happened in a city in Missouri. The installation was an alum and lime feeder and although our drawing had shown an open T on the discharge line just outside of the dissolver, they had connected a 1¼-in. discharge hose directly to the dissolver outlet. There was only about a 4-foot drop to the point of application, but the end of the hose was submerged below the water level. A few days after the feeder was put into operation, they called for a serviceman and stated that the alum solution was apparently clogging up the hose. After watching the machine operate for a short period of time, it seemed quite obvious that there was air binding in the discharge line.

We mentioned this to the superintendent, but he was thoroughly convinced in his own mind that this could not be the problem. He said he could not understand how it was possible for a few bubbles of air to resist the 4-foot head from the dissolver. After assuring him that if our remedy did not solve the problem, we would give him a new piece of hose, he allowed our man to take a pocket knife and make a hole about ¼-in. in diameter in the top of the hose just where it connected to the dissolver. As soon as the hose was punctured, there was a slight gush of air and from then on the solution began to flow readily out of the dissolver.

Wrong Meter

Another experience, in a southern city, involved a Fluoridizer installation which was engineered to operate by proportional control. Specifications called for the flow to be measured through a 14-in. orifice plate, signals to be electrically transmitted through a Chronoflo Transmitter and Chart Recorder. After the installation had been made, the utility complained that there was a marked discrepancy between the readings on the Builders Chronoflo Meter and their existing master meter. The Chronoflo readings followed the master meter readings up to 3 mgd. Beyond that point, the Chronoflo read as much as 1 mgd lower than the master meter.

It is sometimes difficult to diagnose troubles when the patient is 600 miles away from the doctor, therefore, we sent a man to investigate. He found, much to his surprise, that instead of installing the orifice plate to measure the flow, they had made a last minute decision to tap onto their existing Venturi tube on their main discharge line from the plant. The maximum range through that 14-in. x 8-in. tube with their master meter was 0.291 to 5.82 mgd, but the design of the proportional control was based on an orifice plate using a Builders Chronoflo with a measuring range of .82 to 8.2 mgd utilizing 240-in. of water differential. The remedy, of course, was to provide the necessary parts to utilize the Venturi meter.

What—No Broom?

These experiences are not entirely without their humorous side: A city in Ohio has several Omega Gravimetric Feeders, one of which is equipped with a rubber-bladed rotor to prevent flooding of the material through the mechanism. A call from the operator said that the rotor mechanism was not operating proper-

Ed. Note: This article is based on a talk given by the author before the New England Water Works Assn.

ly and material was flooding. It was suspected that something had become lodged in the feeding throat and was probably bending the rotor blades, thus breaking the seal and permitting material to flood through. We instructed the operator to remove the rotor mechanism after the hopper was emptied, and to report back the symptoms so that we might advise him what remedy was needed. We were, of course, prepared to send a serviceman if the operator could not solve the problem.

Two days later, a letter from this Superintendent, read in part, as follows:

"I have just made a very interesting observation and have come to the conclusion that your feeders positively will not feed broom handles."

In filling the hopper, one of the operators had used a long pole to level up the material in the hopper and it got away from him.

'Tain't Funny, McGee!

Someone once asked an equipment manufacturer why they couldn't build equipment that was foolproof. The manufacturer replied, "It can't be done; fools are too ingenious." That quip, of course, is not intended to reflect in any way on the integrity or ability of water plant operators.

The following experience happened in a water treatment plant of a large industrial concern. They reported that an Omega belt feeder was not feeding accurately. A service engineer was sent to check the installation. He observed the feeder in operation and the scale beam seemed to be sensitive enough and apparently acting under normal conditions. Gravimetric feeders are so constructed that if for any reason chemical feeding becomes erratic or inaccurate, the scale beam will immediately go out of balance and an alarm bell will ring to warn the operator.

The service man was baffled because apparently nothing seemed to be wrong, but he made a complete checkup before leaving and quite by accident peered up into the feeder. Thus, he discovered that the scale beam had been cleverly tied with a very fine wire which would permit the beam to oscillate, but not enough to go out of balance.

We could only assume that since this ingenuous operator was on the night shift, the ringing of the alarm bell disturbed his sleep and that he resented having to get up in the night to remedy the trouble or to fill the hopper. They say that lazy people always make the best inventors and you can take it from me that this fellow really did a job on that scale beam. His work was a masterpiece of concealment.—P.S. "Willie doesn't work there any more."

And The Wind Blew

The most baffling experience happened on a Gravimetric Feeder installation in upper New York State. The superintendent wrote that the feeder would not operate properly and that the sentinel alarm rang continuously no matter what they tried to do in the way of adjustment. He said the ringing of the alarm could not be stopped without shutting down the feeder.

A service man was dispatched to perform the usual close checks, but he could find nothing wrong. The hopper was filled with material and the feeder started. It ran continually until it had fed all but a pound and a half of the chemical. During this entire period, the machine functioned normally and the scale beam stayed in balance. The Superintendent was exasperated. He guessed that the trouble was probably due to the fact that his six operators had six different versions of how this feeder should be run, and apparently got so mixed up with their own method of trying to run it that not one of them could run it correctly for any length of time. After this demonstration, he was satisfied that there was nothing wrong with the feeder.

Two days later a telephone call from a very indignant superintendent said to "get up here at once or else." When the serviceman arrived, the feeder was operating normally again. More perplexed than ever he decided to take a walk around the plant to do a little deep thinking. His walk took him upstairs to the chemical storage room and being naturally curious, he inspected the discharge duct which extended from the dust collector unit to the outside of the building. This line was equipped with a damper and our serviceman started fiddling with this damper to see if it was working freely. He left the damper open for about a minute, and, lo and behold, the alarm bells on the feeder downstairs started ringing like mad.

"No, this just can't be," he said to himself, but there it was. Outside, rather strong wind was blowing in the direction of the dust duct. The velocity of the wind blowing back through the dust duct was great enough to upset the balance of the delicate scale mechanism, causing the alarm to sound. Then the superintendent and operators recalled that on the days when the feeder gave trouble, the wind was blowing sharply. As a check the damper on the exhaust duct was closed, the feeder scale beam went into balance and the alarm bell stopped ringing. By way of a permanent remedy, the damper was removed from the exhaust duct and an elbow pointing downward installed outside the building.

Tattle Tale

An Illinois plant Superintendent reported that chart recorders on the chemical feeders presented damaging evidence against an operator who was not handling his job properly. It seems that this operator was scheduled to fill the feeder hopper every morning at 7 o'clock. He would lock the scale beam on the Loss-In-Weight Gravimetric Feeder, to keep it steady while filling. After moving the balance poise out to the end of the 500-pound capacity scale beam, he would go upstairs and fill the hopper.

The operator knew that the Superintendent was not in the habit of arriving at the plant until about 8 o'clock, so at about ten minutes to eight, the operator would come downstairs, unlock the scale beam, and balance out the poise on the scale beam. The scale beam capacity was 500 pounds, but apparently the operator had dumped only about 440 pounds in the hopper. Since the rate of feed was set to deliver 37.5 pounds per hour, 30 pounds were delivered in this 50 minute period, leaving 410 pounds in the hopper. So at 7:50 A.M. when the operator came downstairs and balanced the scale beam, the poise was moved back to 410 pounds. Since the poise had previously been moved out to the 500-pound mark on the scale beam, this showed on the recorded chart supposedly as the amount he had dumped into the hopper to begin the shift's run. Substracting 410 from 500 gave 90 pounds as fed during this 50-min. period.

Since moving of the counterpoise registers a corresponding distance on the chart recorder, representing pounds fed, the error showed up glaringly and forced the operator to give an account of what he was doing between 7 o'clock in the morning and ten minutes to eight. All denials of misdeeds by that operator were to no avail.

It Can't Happen Here

During World War II a hurry-up call came from an Ordnance Plant in Iowa. Omega feeders and slakers were being used to feed quicklime to soften the extremely hard water found in the gravel beds of Central Iowa. Every day or two, the lime slaker clogged up because of carbonate plating out on the sides of the slaker and on the impeller. The high-speed impellers turning at about 800 rpm were so caked up with material that they looked like large coconuts. The 1-3/16-in. diameter tapered shafts on the mixers looked like baseball bats. Such an occurrence was simply unheard of.

The first check was to ascertain if the water temperature was high enough to insure efficient and complete slaking. It was — — — so it was assumed they were using a water-to-lime ratio of 4 or 5 to 1 in order to obtain the high operating temperatures. This was not the case. They had a large supply of warm water available from a heat exchanger and all of this water was being diverted into the slaker. Instead of a 4 to 1 water-to-lime ratio, they were using a ratio of about 14 to 1, and softening was taking place in the slaker, and the velocities caused by the high-speed mixers, calcium carbonate was plating out. The remedy was to reduce the water supply to the slaker to about a 6 to 1 water-to-chemical ratio.

Reverse Safety

At another plant, the operators were afraid to operate the slaker at high temperatures, although high temperature slaking is proper and more economical. The temperatures never should be permitted to fall below 160°F. To prove that there is no danger in operating slakers at this temperature, servicemen start up slakers, at temperatures up to 190° and 200° F.

Nevertheless, in this plant, although the day shift operated slakers at 150° to 160°F., the night shift, wanting to play safe, opened up the water valve and let the temperatures drop to 100° to 110°F. Operating at these extremely low temperatures resulted in considerable unslaked lime leaving the slaker. On one occasion, this unslaked lime gradually built up in a 6-in. discharge line so that finally the discharge line, (built large to avoid stoppage) completely filled up and the slaker started to overflow. The operator, noting the difficulty, picked up a piece of reinforcing bar, which had previously been used to rod out the discharge line whenever it showed signs of plugging up. This time, however, the moment he tapped the plug in the discharge line, it blew up in his face and caused severe burns.

What happened? — — Large particles of unslaked lime had settled in the discharge pipe, continued to slake and as they slaked, more heat was evolved so that neighboring particles of lime which only needed heat to make them slake properly, also started to slake. When all the available water in the pipe was used up, steam began to form and the operator happened along just at a time when the pressure built up in that pipe was extremely great. The moment he made a hole in the plug of lime, the steam rushed upward like a geyser.

Some Things Don't Mix

At one installation, chemicals are hauled from a freight siding some distance away by truck into the plant and an inclined screw conveyor is used to elevate quicklime and ferrous sulphate (copperas) into overhead storage bins. The same screw was used for both chemicals and proper gates opened to allow the right chemical to go into the right bin. A small leak developed at one of the connections to the screw so that a thin stream of chemical sifted down onto a boardwalk below the conveyor during the loading operation.

In one instance, both copperas and quicklime were loaded the same day. Sometime near the end of the filling operation, it was noted that the boards below the conveyor were burning merrily.

What had happened? — — — The lime had absorbed some of the water of crystallization in the copperas causing it to slake. As it slaked, the temperature rose, increasing the speed of the reaction. Soon, the small mass of mixed quicklime and ferrous sulphate reached combustion temperature and the boards broke into flames.

There have been similar instances of fires or charring of filter bags in vacuum type unloading systems where the same system is used for ferrous sulphate and quicklime.

In another instance, the same conveyor system was used to elevate alum and quicklime to steel storage bins. The alum bin and the quicklime bin were adjacent and the operator manipulated valves in order to direct the chemicals into the proper bin. With such installations, it is inevitable that mistakes are bound to occur and in this case, our engineers warned what might happen. In the interests of economy, however, a single elevator was installed.

The inevitable happened when, within a few months, alum was dumped into the quicklime bin. The bin began to heat up, paint began to smoke and peel off of the steel bin and the fire department was called. They very wisely decided against putting water into the bin which could very well have caused the quicklime to explode. Presumably the firemen played water on the outside of the bin to keep the temperature down as much as possible to prevent the bin and steel supporting members from buckling, but the final "melt" had to be dug out of the bin by men with picks and axes.

Wrong Way Corrigan

In a large industrial waste treatment plant in Michigan, the equipment was installed by the contractor and merely had to be checked and given a final inspection by the servicemen of the various equipment manufacturers. The plant superintendent confidently set a date for starting up with the hope that all they would have to do would be to go around and push buttons and the plant would start to function. There were several chemical feeders and a couple of lime slakers so that probably a dozen motors were involved insofar as Omega equipment was concerned. Our serviceman arrived early in the morning and when he started up the machines, he found four motors running backwards. This represented one third of the motors on the Omega equipment turning in the wrong direction. This seemed a rather high percentage and after reversing the leads on these four motors to make them run properly, he called the Superintendent's attention to the fact. Together they found a centrifugal pump and a exhaust fan also running backward.

The Superintendent decided to postpone starting the plant for another day so that he could make a complete inspection of all motors. "Believe it or not," in this plant they found a total of 29 motors turning in the wrong direction.

If these incidents have any moral, I believe it is that servicemen sent out by equipment manufacturers can be most helpful, not only because of their familiarity with the specific equipment involved of their own manufacture, but because of their background, general knowledge and experience gained from the sort of situations outlined in this paper.

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COAGULATION AND SEDIMENTATION

THE PRESENCE of turbidity, suspended matter, bacteria or other organisms in water makes it unfit for domestic uses. Removal of the undesirable constituents is one of the purposes of water treatment plant. In sewage treatment the removal of suspended matter is essential to reduce the nuisance characteristics of the sewage. The unit processes which remove these undesirable substances from liquids are coagulation and sedimentation. In most water works, coagulation and sedimentation go together. In sewage works, sedimentation without coagulation is the usual practice, except where chemical treatment is used.

Definitions

Coagulation is the addition of a chemical to water or wastewater, whereby it reacts with other chemicals in or added to the liquid. The result is floc, which, by nature will enmesh and "sweep out" settleable, non-settleable, and colloidal matter in the liquid.

The chemicals used, called *coagulants,* must be carefully added in correct amounts; this is known as *dosing.* After addition of the coagulant, it must be thoroughly and quickly dispersed throughout the liquid being treated; this is known as *mixing,* and is accomplished by stirring devices. Following dispersion of the coagulant, the liquid is slowly stirred while the flocs grow in size and pick up impurities; this is called *flocculation.*

Sedimentation is the process by which the influence of gravity causes particles of suspended matter, and flocs to settle out of slowly moving or quiescent liquid. The rate of movement of the liquid must be slow enough to prevent the settled matter from being picked-up or resuspended by scouring action. Sedimentation is sometimes called clarification, but clarification generally refers to the combination of coagulation and sedimentation when both are employed.

Coagulation

The function, theory, control and operation of the coagulation process is the same for water and sewage treatment and the choice of coagulants may be the same, although some water and sewage plant operators have preferences in coagulants.

Most popular coagulating agents are the salts of aluminum and iron. Aluminum sulfate, generally called "filter alum", is generally used for water treatment. Ferric sulfate has been used for both water and sewage treatment. Ferrous sulfate (Copperas) can be used in water treatment with lime; it is not used in sewage treatment. Chlorinated Copperas is a mixture of ferric sulfate and ferric chloride produced by the addition of chlorine to ferrous sulfate on the site. Ferric chloride is used as a coagulant in the dewatering of sewage sludge for vacuum filtration. Aluminum chloride has been used for sludge dewatering where it is available as a waste material.

As aids to coagulation, other chemicals are sometimes added. One of the most effective is activated silica, produced at the site from sodium silicate and an activating agent such as chlorine, alum, carbon dioxide, sulfuric acid, etc.

Factors which influence the coagulation of turbid and colored waters includes: kind and quantity of coagulant, amount and character of suspended and colloidal matter, pH of water, mixing and flocculation time, liquid temperature, violence of agitation, presence of nuclei, etc.

The application of the correct amount of coagulating chemical is done by chemical feed machines, which may be controlled manually, automatically or paced by the flow of liquid. Determination of the proper chemical dosage is done by coagulation control tests, commonly called jar tests.

Sedimentation

The theory of sedimentation, is that under the influence of gravity, particles heavier than water tend to settle downward at a rate which depends on their size, weight, shape and on the resistance, or viscosity, of the liquid.

The purpose of sedimentation tanks is to remove as many settleable particles as is possible in the time available. To accomplish this, tanks are designed to produce the lowest possible rate of flow through the tank during the period of sedimentation. The shape of the tank may be circular or rectangular and depths may vary according to designers' preferences. Rate of flow through the tank, or the overflow rate, is based on the size of the particle to be removed in the time allotted.

Some tanks, particularly for use in water softening, called upflow-clarifiers, utilize vertical up-flow, usually through a sludge blanket at the bottom. These tanks combine the process of coagulation, flocculation and sedimentation all in one unit.

According to the theory of sedimentation, a particle settles according to its size and specific gravity. That fact can be made us of by controlling the velocity of flow so that heavy particles, such as sand, grit, etc., will settle out while lighter organic particles will be carried on to be removed later in sedimentation tanks. The design of grit chambers is based on this principle of differential sedimentation.

Sludge Removal

Wherever there is sedimentation the mass of solids removed is called sludge. Sludge, whatever the kind (coagulation, water softening, raw sewage, or activated sewage) must be removed from the sedimentation tanks. To accomplish this removal, many modern sewage and water plants use continuous sludge removal by scrapers. These scrapers operate continuously or on a timed cycle to move the sludge to a single sump, from which it can be pumped to a sludge disposal point. The design of sludge scrapers is directly related to the shape of the sedimentation tank. Some sedimentation tanks, the Imhoff tank for sewage treatment, and the upflow clarifiers utilize hydraulic transmission of sludge from sludge storage hoppers to point of disposal.

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Coagulation Control Tests*

JAR TEST PROCEDURES

LABORATORY control is necessary to proper coagulation treatments, because (1) plants which employ coagulation usually treat surface waters subject to wide variations in characteristics, and (2) the best and most economical treatment of such waters cannot be calculated, but must be determined at frequent intervals by coagulation control tests. Commonly called a "jar test," this is a method for determining the optimum or best dosage of a coagulant.

NEED FOR LABORATORY STIRRER

The quick addition of coagulant solutions to samples of the water is a very important part of the test. Equally important, is the rapid mixing to disperse the chemicals in the water, followed by a slow mixing action to effect coagulation and flocculation.

Hand stirring of the samples cannot give the same effect in each sample, or in different tests; neither does it reproduce the action of coagulant mixing and flocculation in the plant. Use of a multiple laboratory stirrer (Fig 1) makes it possible to (1) determine the optimum dosage from one test, (2) duplicate conditions or previous tests, and (3) simulate mixing conditions in the plant.

Square Mason jars of approximately 2 qt capacity should be used, or 2000 ml battery jars or beakers. Square jars provide better mixing characteristics than round jars or beakers.

PREPARATION OF STOCK SOLUTIONS

The common coagulants used are filter alum, ferric sulfate, sodium aluminate, or ferric chloride, and the common coagulant aids include lime, soda ash, activated silica and Bentonite.

The first step in the procedure is to prepare stock chemical solutions. Modern techniques express chemical dosages in "parts per million" (ppm), but many operators still use "grains per gallon" (gpg), while others report coagulation dosages in "lb per mil gal." Whatever unit of dosage is used, the stock chemical reagent solution should be made in a concentration, whereby 1 ml of solution in 1000 ml of water, will be equivalent to a unit of dosage.

TABLE 1
Reagent Stock Solutions

Wt. of Chemical grams/liter	Dosage Value of 1 ml/1000 ml
10.	10 ppm
17.1	1 gpg
5.975	50 lb/mil gal

Table 1 gives the weight of chemical to add to a liter of distilled water in order that 1 ml of solution added to 1000 ml of water will equal a dosage of a definite number of units. The chemical reagent solutions should be made from samples of the chemicals used in treatment, not from laboratory reagents.

Conversion factors to change one system of reporting dosages to another is shown in Table 2.

TABLE 2
Conversion Factors for Calculating Dosages

Units	ppm	gpg	lb/mil gal
Parts per million	1.0	0.058	8.34
Grains per gallon	17.1	1.0	143
Pounds per mil gal	0.12	0.007	1.0

To avoid an appreciable change in volume of sample when the coagulant is added to the sample in the jar, the stock solutions are generally made in the concentrations shown in Table 1, but other concentrations may be used.

NOTE: (1) When lime is added to water, a suspension is produced. Agitate this suspension and mix thoroughly before any amount is withdrawn for treating the water sample. (2) Weak solution of alum can be stored satisfactorily, but ferric sulfate solutions hydrolyze rapidly. To avoid deterioration of ferric sulfate reagent solutions, the following technique of preparation is used: Add 1500 grams of ferric sulfate (Ferriclear or Ferrifloc) to 500 ml of distilled water at 71°C (160°F) and stir it rapidly for 30 min. Cool to room temperature, and add 500 ml of distilled water. This stock solution contains 0.5 gram per ml.

For reagent solutions, dilute 4 ml of this stock solution to 100 ml with distilled water. One ml of this diluted reagent solution contains 20 mg of ferric sulfate and when added to 1 liter of sample, is equivalent to a dosage of 20 ppm. This reagent solution is not stable for more than 10 hr and should be made fresh daily.

(3) Sodium aluminate is made by diluting the commercial solution to the strength desired.

(4) Activated silica reagent must be made as it is used.

(5) When not in use, all stock solutions should be kept in tightly stoppered bottles. Fresh stock solutions should be made at least every two weeks.

TEST PROCEDURE

1. Measure 1000 ml samples of raw water in a graduated cylinder or volumetric flask and transfer to the jars under the laboratory stirrer (Fig 1). Use at least three samples and preferably five or six. (The water should be at the same temperature as exists in the treatment process and the tests should not be carried out in the direct sunlight.)

2. Number the jars in sequence and record experimental dosages to be used in each, using a record sheet similar to that shown below.

3. Start laboratory stirrer at 150 rpm, after the samples of water are added to the jars and immediately preceding addition of chemical reagents to the jars.

Fig. 1—MULTIPLE laboratory stirrer

4. Add chemical reagent solutions to samples in this manner: (a) As nearly as possible, add any one chemical simultaneously to all jars. (b) Add chemical reagents in the same order to the sample as chemicals are added in plant practice. (c) Where lime (or soda ash) is used, add it before the coagulant. (d) If chlorine is added before coagulants in the treatment

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COAGULATION TEST RESULTS

Source _____ By _____ Date _____

Jar No.	Temp °C	Turbidity	Color	Alkalinity	pH	Dosage ppm-gpg		Test Duration Minutes			Floc		Filtrate			pH
		Parts per Million				Alkali	Coagulant	Mix	Stir	Settle	Time to Appear Min.	Index	Color	Turb.	Residual Alumina	
													Parts per Million			
1																
2																
3																
4																
5																
6																

FLOC INDEX FOR TESTS

0 – No Floc 2 – Smoky 4 – Pin Point 6 – Fair 8 – Good 10 – Excellent 12 – Very Heavy

Fig. 2—RECORD sheet for coagulation jar test

process, add a chlorine solution to the sample jars, unless it is found that chlorination has no effect on coagulation.

5. Continue rapid mix for three minutes. (If lime is used, add it and stir at 150 rpm for 1¼ min before coagulant is added, then mix for three min.)

6. After the rapid mix period, reduce the speed of stirrer to 32 rpm and stir at that rate for 15 min.

7. Record the time it takes for the first floc to appear in each jar and record the Floc Index at end of stirring period.

8. At the end of the slow-stirring period, stop the stirrers and allow the floc to settle for 30 min.

EVALUATION OF RESULTS

Determine optimum dosage for water treatment by: (1) Visual observations, (2) analysis of settled sample, and (3) analysis of filtered sample, or preferably all three.

After the settling period, choose samples which show a Floc Index of 6 or better. On the settled or filtered samples determine turbidity, color, pH, and, if desired, residual free alum (or iron) in solution. Record data on sheet like Fig. 2.

(NOTE: Obtain filtered samples by pipetting 200 ml from a point at half depth of the sample in the jar. Transfer this volume to a funnel containing a wad of absorbent cotton. Collect filtrate in a 250 ml Erlenmeyer flask, numbered to correspond with test jars. If larger quantities of filtrate are desired, be sure not to disturb settled floc while removing the sample from a test jar.)

Results obtained, as well as mixing and stirring speeds and times must be correlated to plant practice and standardized to produce laboratory scale results that will indicate best plant dosages.

APPARATUS RECOMMENDED

1 - Laboratory Stirrer (six-unit with speed range from 32 to 150 rpm—See Fig. 1.)
6 - 2 qt square Mason jars, (battery jars or beakers)
1 - 1000 ml graduated cylinder or volumetric flask
2 - 5 ml pipettes, graduated in 0.1 ml
1 - Thermometer (Centigrade)
1 - 100 ml volumetric pipette
6 - 250 ml Erlenmeyer flasks
6 - 85 mm funnels
2 - 1000 ml glass stoppered reagent bottles
1 - pH meter (electric) or pH colorimeter
1 - 1 lb package of absorbent cotton
1 - 2 gal bucket with rope for collecting samples

Record sheets (Fig. 2) of the type shown here may be obtained from Omega Machine Co. on request.

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The Chemistry of Water Coagulation

By A. P. BLACK*

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It is well for those of us who are engaged in any phase of water treatment to occasionally review the basic principles having to do with the processes being employed. These articles are prepared with that in mind. They do not purport to contain any material which is new or original and no references to the literature will be cited. They have been prepared with the idea of briefly summarizing the most important chemical principles underlying certain processes of the chemical treatment of water. Part I will deal with coagulation; Parts II and III with softening and corrosion control, respectively.

Coagulants may be defined as those substances which are capable of removing colloidal impurities from water, and coagulation is the process by which such removal is brought about.

As we look back over what has taken place during the past seventy-five years, it seems rather clear that the development of coagulation as an art was greatly influenced by the development of slow sand filters, the first of which was constructed in 1829 by James Simpson of the Chelsea Water Company, London. Its effectiveness for the purification of water is too well known to require discussion here. It was early noted that its efficiency was greatly improved after the formation on the surface of the sand of a slimy gelatinous coating which was and still is termed "Schmutzdecke." There seems little doubt but that when early American workers began their development of the rapid sand filter it was their desire to duplicate by chemical means this slimy coating or schmutzdecke on the sand.

Since a chemical was to be used, however, it had to possess certain qualifications. It must, first of all, be gelatinous in nature so as to resemble as nearly as possible the organic growths on the older slow sand filters. Furthermore, it must be non-toxic, it must be relatively inexpensive, and it must be capable of reacting either with water itself or with substances naturally present in water or which might be added to water so as to produce the necessary gelatinous precipitate. As we all know, aluminum sulfate or a filter alum was selected for study. Although many years have passed since alum was first used for this purpose, it is probably true to say that it is still the most widely used of all coagulants in water treatment.

It is the purpose of this paper to show that the remarkable properties of filter alum as a coagulant are not due to its gelatinous nature but to entirely different properties unknown to the earlier workers. It is one of the most remarkable coincidences in contemporary science that after the real mechanism of coagulation became known, filter alum still remained the most widely used of its class.

It is possible to write equations for the chemical reactions which take place when aluminum sulfate is added to water containing natural alkalinity or added alkalinity in the form of lime or soda ash. These are show below:

1. $Al_2(SO_4)_3 \times H_2O + 3\ Ca(HCO_3)_2 = 2\ Al(OH)_3 + 3\ CaSO_4 + 6\ CO_2 + (X-6)H_2O$
2. $Al_2(SO_4)_3 + 3\ Ca(OH)_2 = 2\ Al(OH)_3 + 3\ CaSO_4$
3. $Al_2(SO_4)_3 + 3\ Na_2CO_3 + 6\ H_2O = 2\ Al(OH)_3 + 3\ Na_2SO_4 + 3\ CO_2$

While it is probable that there are cases where these reactions take place essentially as they are written, it is also probable that there are many cases where they do not go about it in exactly this manner. In order to understand that statement and the true mechanism of coagulation, it is necessary to examine the nature and properties of colloids.

Colloids, Their Classification and Properties

The colloidal phase refers to any form of matter in a certain state of subdivision or, better, within certain limits of particle size. The unit of measurement to be used is the millimicron or mμ. This is one-millionth (0.000,001) of a millimeter, which is approximately one twenty-five millionth of an inch. While no definite limits may be set within which various phases of matter may be grouped, it is possible to state that the molecules and ions of true solutions usually vary in diameter from 0.1 to 1 mμ. The particles in the colloidal phase will usually fall between 1 mμ and 100 mμ; above the higher figure they merge into the suspensions and emulsions which may be separated more or less readily by physical means.

A solid or particle size between 1 and 100 mμ when dispersed in a liquid is called a suspensoid, and a liquid the droplets of which vary in diameter from 1 to 100 mμ when dispersed in another liquid is called an emulsoid. Both are colloids. In most respects colloids resemble true solutions; in ordinary lighting they are clear and transparent, they will not settle, and they may be filtered without removal of the colloidal material. Under proper lighting conditions, however, a bright beam of light passed through a colloidal solution produces what is called a "Tyndall Cone" which results from the reflection of part of the transmitted light by the tiny particles. Under the ultra-microscope colloidal particles are found to be in constant motion. This motion, termed the "Brownian movement," results from the bombardment of the tiny colloidal particles of the colloid by the rapidly moving molecules of the solvent. The boiling point, freezing point, osmotic pressure and vapor pressure of colloidal solutions are essentially identical with those of the pure solvent.

Colloids may be classified in a number of ways. In the first place, they may be classified as sols or gels. Sols are, of course, colloids which have the appearance of true solutions, whereas gels have a jelly-like structure from which the name colloid (Greek: Like glue) was derived. Sols and gels may be readily demonstrated by anyone by two simple experiments. For the first experiment, one takes two 1-liter beakers, one containing boiling distilled water and the other distilled water just above the freezing point. If to each beaker there is added two or three drops of a saturated solution of ferric chloride a most interesting contrast will be noted. The beaker containing the cold distilled water will exhibit only the very faintest color of the dissolved ferric chloride, hardly perceptible to any except the trained eye; the other beaker, however, assumes a deep wine-red color. The explanation of course is that at the temperature of boiling point the ferric chloride is hydrolized with the formation of colloidal ferric hydroxide and soluble hydrochloric acid. This ferric

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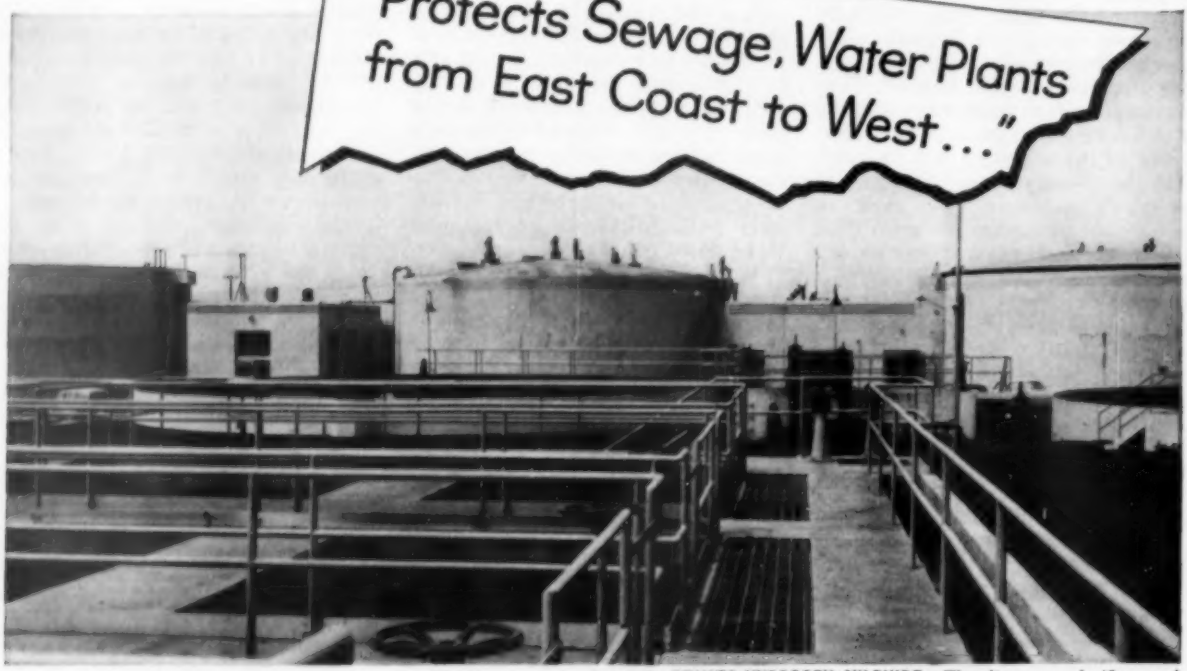

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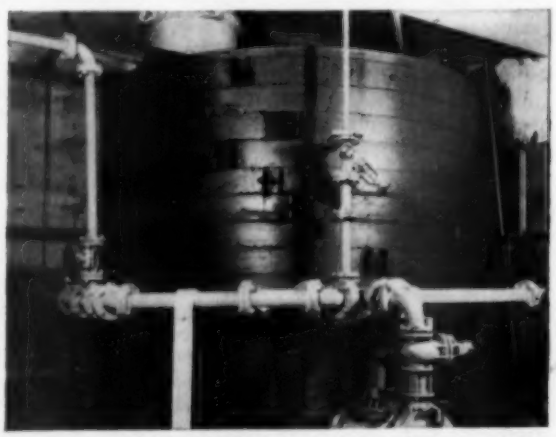

...AND FERRIC CHLORIDE—This 3,500 gal. ferric chloride storage tank in the vacuum filter plant, Back River Sewage Works, Baltimore, Maryland is covered with three coats of red Rubalt RA paint based on Parlon, manufactured by Alfred Hague & Company, Brooklyn, New York. Parlon finish was only one found able to resist corrosive effect of ferric chloride, which is so strong that it will eat away bare metal or concrete. Tanks are wood with rubber liner.

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hydroxide sol is crystal clear and may be filtered through the finest laboratory filter paper unchanged. If the cold beaker be set aside for a few hours or over night, it will gradually color up until the same wine-red intensity is finally reached. If both are allowed to stand for a few days a reddish gelatinous precipitate of ferric hydroxide will result in each. This is due to the fact that other ions present in the solution will finally cause precipitation. If, however, these colloids are dialized and these foreign ions removed, the colloidal solution will be stable almost indefinitely. The writer has in his possession and has many times shown colloidal solutions of ferric hydroxide, of metallic silver and metallic gold, which are at the present time fifteen years old and which have maintained their strength essentially unchanged during that period.

Another simple experiment may be used to demonstrate the formation of a gel. In one beaker is placed 30 ml. of a clear saturated aqueous solution of calcium acetate. In a second beaker there is measured out 170 ml. of 95% ethyl alcohol. If now the alcohol is rapidly poured into the clear limpid solution of calcium acetate and then an attempt is made to pour the mixture back into the first beaker, it will be found that the mixture has set to a solid gel before the transfer can even be begun. This gel is so stiff that it may be penetrated by the finger only with difficulty, yet it is formed within a matter of moments from two clear free-flowing solutions.

Colloids may be classified as reversible and non-reversible. Ordinary starch solution is an excellent example of the former. If a little starch is added to boiling water and the mixture boiled for a few minutes, a clear, faintly bluish solution results. When allowed to cool it sets to what is termed "starch paste." However, if reheated it will again assume the appearance of a solution. Egg albumin or ordinary egg white is an excellent example of a non-reversible colloid. A small amount of fresh white of egg added to water and thoroughly shaken yields what appears to be a true solution. If now this mixture is boiled the egg white is coagulated and it may not be again transformed to its original state since a permanent change in the material has taken place.

Colloids may be classified as lyophobic and lyophyllic. This classification has to do with the affinity of the colloidal particles for the dispersing medium. If the attraction between the colloidal particles and the dispersing medium is small, the colloid is termed lyophobic. If, on the other hand, the attraction between the colloidal particles and the dispersing medium is great the colloid is termed lyophillic. The viscosity of lyophobic colloids is usually about the same as that of the medium, and they are quite susceptible to coagulation. The viscosity of lyophillic colloids, on the other hand, is usually much greater than that of the pure medium. In water treatment we deal for the most part with lyophobic colloids.

Finally the most important of all, colloids may be classified as positive or negative since it may readily be shown that they bear electrical charges. There are a number of theories as to the source of this electrical charge, but these are beyond the scope of this discussion. It is sufficient for us to know that the particles of some colloids bear a positive charge whereas the particles of other colloids bear a negative charge. It is also true that colloids may be prepared in essentially neutral condition and it is further necessary to note that colloids may change their electrical charge from positive to negative or the reverse as a result of a change or changes in external conditions. The latter point is very important in the theory of coagulation since it has been shown by numerous workers that both aluminum hydroxide and ferric hydroxide flocs may be either positive or negative. This has a most important bearing, not only on floc formation, but also on the completeness with which a coagulant will do the job it is supposed to perform.

Methods of Precipitating Colloids

Colloids may be precipitated in a number of ways. Three will be mentioned since each of these has found applications or plays a part in water treatment.

The first is by electro-phoresis. This rather involved word simply means the precipitation of a colloid of one sign on an electrically charged pole of opposite sign. As a specific example, if we immerse two electrodes in the beaker of ferric hydroxide sol whose preparation was described earlier in the paper and pass a direct current through the sol, the wine-red color may be observed to slowly drift toward the negative electrode and a precipitate of gelatinous ferric hydroxide forms on and below that electrode. Since the colloidal ferric hydroxide particles have moved to the negative pole we may assume that before they were neutralized they bore a positive electrical charge. There are, on the other hand, various colloids which when placed between charged electrodes will move to the positive pole. These, of course, are negative colloids.

It is interesting to remark at this point that the two types of impurities for which coagulation is most commonly employed, namely color and turbidity, are both present in water in the form of negative colloids. This point is emphasized since it is most important in the discussion to follow. During the past few years a number of devices employing this principle of electro-phoresis have been suggested for practical use under various trade names. They have not been particularly successful due to polarization of the electrodes and frequent cleaning which is necessary.

Colloids may be coagulated by other colloids of opposite sign. For examle, if to a negatively charged colloidal sol there is added an equivalent quantity of a positively charged sol, something akin to neutralization takes place and a precipitate is formed which consists of the mixture of the two substances originally present. This is most important in connection with coagulation of a water and will be referred to again later.

In the third place, and most important of all, colloids may be precipitated by ions of opposite charge. For example, if to a stabilized ferric hydroxide sol bearing a positive charge a little hydrochloric acid is added, the sol will be precipitated by the negatively charged chloride ion. This is the explanation for the ultimate precipitation of the ferric hydroxide hydrosols whose preparation has been described. There is, however, a very great difference in the relative precipitating power of ions and this power results from the value of the charge carried by the ion. Keeping in mind that in a discussion of this sort, only very general statements can be made, it is possible to say that as a rule the precipitating power of a bivalent ion will be 50-60 times as great as a monovalent ion and the precipitating power of a trivalent ion will be 600-700 times as great as that of a monovalent ion.

It is this remarkable fact which throws most light on the action of soluble aluminum and ferric salts as coagulants in water treatment. It may be demonstrated by dividing a positively charged ferric hydroxide sol prepared as described above into three equal portions. To one there is added a small amount of sodium chloride. To the second is added an equivalent amount of sodium sulfate and to the third is added an equivalent amount of one of the soluble sodium ortho-phosphates. The sodium chloride will have very little effect in precipitating the sol, the effect of the sodium sulfate

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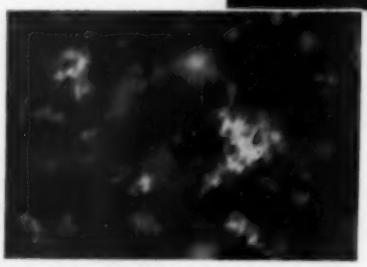
N-Sol® activated silica used with alum, ferric salts or other coagulants forms a large, bulky, strong floc at a faster rate than when the coagulant is used alone. The N-Sol floc entraps impurities and suspended matter, settling rapidly to produce clear, sparkling water. Silica sol coagulant aid is effective in all popular flocculating and sedimentation equipment for a wide variety of waters.

Activated silica sol is made with N Silicate of Soda (41° Baume) and a reactant chemical at the plant where it is used. PQ's N-Sol Processes using reactants as noted below are licensed without royalty. (The use of sulphuric acid is covered by U. S. Pat. 2,217,466, J. R. Baylis, City of Chicago.)

Coagulation with alum alone



Coagulation with alum plus activated silica sol

PQ Assistance

Samples of N Silicate of Soda and directions for making jar tests are available on request. PQ engineers are glad to share our experience with activated silica sol as an aid in water treating problems. Ask for free booklet, "Treatment of Raw and Waste Waters."

COAGULATION	PROCESS	REACTANTS	ADVANTAGES
Raw Water Improves quality Lengthens filter runs Removes high color Reduces turbidity Removes manganese Removes magnesium	N-SOL-A (U.S. Pat. 2,444,774)	ammonium sulphate	Ease of preparation, either batch or continuous. Requires smaller equipment.
Waste Water Prevents stream pollution Clears effluent	N-SOL-B (U.S. Pat. 2,310,009)	alum	Reactant readily available, inexpensive.
In Such Industries as: Paper Petroleum Metal Finishing Plating Food Textile	N-SOL-C (U.S. Pat. 2,567,285)	chlorine	Reactant usually available where sterilization is normal practice.
Also Radio Active Waters	N-SOL-D	sodium bicarbonate	Used where an alkaline salt is desired. For boiler feed water where ammonia is not desired.

will be very much greater and that of the sodium phosphate greatest of all. If the experiment is carried on in such a manner that quantitative results will be obtained, values for the relative precipitating power of the ions approximating those just given will be obtained.

Having now reviewed some of the chemistry of colloids, we are in a position to examine the known facts of coagulation and to attempt to explain them in terms of the behavior of colloids. We have learned that both color and turbidity present in natural waters are present in the form of negative colloids. That leads us at once to the conclusion that for their coagulation we will need to employ either a positive ion or a positive colloid or both. As it happens both agents take place in the phenomenon of floc formation. We discover now by examining the chemical formulae for filter alum and ferric sulfate or ferric chloride that these coagulants each have a positive ion whose valence is three. Though chemists have carefully searched the periodic table of the elements and have made efforts to employ other elements of the same valence and elements of higher valence, it still remains true that these salts are most effective and most widely used as coagulants.

Mechanism of Coagulation and Floc Formation

When a coagulant is added to water for the removal of color or turbidity three separate factors and three different types of action are involved. They will be discussed in the order in which they take place.

1. As the coagulant dissolves and the trivalent aluminum or ferric ions become available, they neutralize the negative charge on the particles of color or turbidity and, as we have seen, their neutralizing power is very great. This, in the opinion of most authorities, is the most important phase of coagulation and it takes place long before the visible formation of floc particles. It is evident that this action will be more efficient if the coagulant can be brought into intimate contact with the material to be removed before secondary reactions can take place. This clearly implies the desirability of rapid mixing as the first step in coagulation.

2. When the positively charged aluminum or ferric ions have neutralized a considerable portion, perhaps most of the negatively charged colloidal particles of color or turbidity, the resulting particles may be called micro-flocs for the purpose of this discussion since they are still beyond the limits of visibility and far too small to settle under the influence of gravity. Furthermore, it has been shown that, in the acid range of coagulation most commonly employed, they still retain positive charge, possibly due to the adsorption of positively charged hydrogen ions from the solution. We are now dealing, therefore, with a positively charged colloid which has the capacity to neutralize the negatively charged colloid. These positively charged micro-flocs can therefore continue to remove negatively charged particles of color or turbidity, and this constitutes the second phase of coagulation.

3. During both of the above phases no visible floc particles have formed. The mechanical treatment of the water from this point forward should consist of slow stirring, termed by some authors "conditioning" in order that these tiny micro-flocs may cluster together and agglomerate with the formation of floc particles which steadily grow in size until they are in a proper condition for sedimentation. During this phase of floc growth the third action, that of surface adsorption, takes place. It is outside the scope of this paper to deal with the various theories of adsorption, and the complex forces which may be and probably are involved. It is sufficient only to say that the amount of surface area exposed by the innumerable particles of floc is very great and that impurities in the water may be adsorbed on these active surfaces. It should be emphasized however that the formation of a large and well formed floc, while important from the standpoint of sedimentation, is not necessarily the criterion of successful coagulation since the most important functions of the coagulant take place, as has been shown, before the floc ever attains visible size.

Influence of Other Ions Present in Water

It has been stated that the micro-floc particles formed by coagulation with either filter alum or ferric sulfate in the acid range bear a positive charge. This has an important implication to the water chemist since it should mean that a water high in sulfate ion should be coagulated more readily than a water low in sulfate ion or high in chloride ion and that is true. While the precipitating power of the bivalent negative sulfate ion is not as great as of a trivalent ion it is still very high and it is true that sulfate waters are more readily coagulated in the acid range than are chloride waters, and for the same reason ferric or aluminum sulfate are better coagulants than the corresponding chlorides. It follows also that since the ions are charged, each ion present in a given water will have some effect on floc formation, the positive ions in the water interfering with the formation of a positive floc and the negative ions helping in its formation. This is one of the important reasons which explains the individuality of waters as far as their coagulation is concerned. As will be shown in the next paper in this series, the softening of water by any of the known processes follows well defined chemical laws and dosages, and results can be calculated in advance. This is not true with coagulation. The first of the chemical equations which has been listed above presents what would happen if filter alum reacts completely with natural alkalinity present in a water. Assuming for filter alum a "practical" molecular weight of 600, which corresponds to about 14.5 molecules of water of crystallization, one grain per gallon of alum would reduce the alkalinity of a given water by 8.5 parts per million. If pure aluminum sulfate whose formula is $Al_2(SO_4)_3 .18 H_2O$, and whose molecular weight is 666 be used, then the theoretical reduction in alkalinity by one grain of alum is 7.7 parts per million. Every water works operator who is experienced in coagulation is, however, well familiar with the fact that it is possible to add a considerable dosage of alum to a water with alkalinity reduction substantially less than called for by either of these figures. This indicates the correctness of the theories of coagulation which have been set forth above and results from the fact that a considerable fraction of the aluminum ions instead of reacting with the alkalinity of the water react directly with the negatively charged particles of color or turbidity.

In the case of organic color, the flocs formed are called "color flocs" and are quite different in properties and appearance to the gelatinous aluminum hydroxide formed by the reaction of aluminum sulfate with alkalinity in water. Although this is true, it has not been found possible to arrive at equations for calculating the amount, which will hold in every case, for a given coagulant to remove a given amount of color or turbidity from a water. Such equations are published from time to time and are usually valid for the particular water from whose treatment they are derived but as a rule they are found not to hold in case of other waters. This can only mean of course that we do not as yet have sufficient information with regard to the true nature of the

colloidal impurities which we are removing from water. This is particularly true with respect to organic color. After more than fifty years of water treatment, we still find ourselves in the position of using more or less rule-of-thumb methods for the removal from water of a material about whose chemical composition we know relatively little. Much research needs to be done on the fundamental nature of color in water.

Coagulants Used in Water Treatment

It is hardly worthwhile to attempt a complete listing of the coagulants which have been used in water treatment since most water works men are familiar with them and they receive frequent mention in the literature. As has been previously stated, aluminum sulfate continues to be the most widely used material of its kind but there appears to be an increasing tendency toward the use of ferric sulfate. Sodium aluminate often finds application, particularly in industrial water treatment. Ferric chloride and chlorinated copperas have been used and in the Middle West a combination of ferrous sulfate and lime is widely used, mainly for the removal of turbidity. It was one of the first coagulants to be used in this country, having been used by Bull in Quincy, Illinois, in 1898.

The use of Bentonite has been suggested but it has not been generally adopted although it has proved useful in certain cases. The use of activated silica as an accessory coagulant deserves special mention. A solution of sodium silicate, activated with sulfuric acid as recommended by Bayliss, by aluminum sulfate as recommended by Graf and Schworm, or by ammonium sulfate, chlorine, carbon dioxide, and so forth as recommended by Hay and others, yields a stable sol bearing a high negative charge. In the acid range it effectively promotes coagulation and floc formation with either aluminum sulfate or ferric sulfate. It is not generally recognized, however, that activated silica may act as a coagulant in the truest sense of the word since, in softening many waters by the lime-soda process it results in the formation of a better-formed and better-settling sludge than either alum or ferric sulfate. The new 80-million gallon softening plant of the City of Miami is being designed to employ activated silica as the only coagulant although facilities will be provided for feeding alum to anticipate possible changes in water quality. In the case of this particular water a dosage of 2-4 parts per million of activated silica yields better results than a dosage of three grains per gallon of alum. While activated silica used in conjunction with another coagulant should properly be called a coagulant aid, the time has come to recognize that it may and often does act as a coagulant in the truest sense of the word.

Laboratory Control of Coagulation

The most important single tool at the disposal of the chemist in charge of the operation of a coagulation plant is the jar test machine and there is no substitute for numerous and properly conducted jar tests for the control of such plants. Only by such test can the most economical dosage of coagulant be arrived at and the best settling flocs be obtained. There are many excellent papers in the literature describing the proper technique for such tests and they are also described in several of the contemporary text books and manuals. Every operator who does not have a jar test machine and is not using this test, should consult these references and institute such tests if he desires to obtain best results from his plant. Along with the jar test it is necessary to make regular and periodic determinations of color or turbidity, alkalinity, total hardness and pH value. The latter is especially important since it has to do with the stability of the treated water. In the case of most so-called "Filter" plants which employ coagulation, the treated effluent is apt to be quite soft and of relatively low pH value. There are a number of ways by which such waters may be stabilized and that subject will be discussed in one of the other papers which are to follow.

The ever-increasing popularity of the newer types of up-flow equipment emphasizes the need for a better understanding of coagulation since retention times are far less in these types of units than in the older and more conventional settling basins. For the same reason a great deal more vigilance and careful supervision is indicated in the operation of such plants. It is doubtful if anywhere in American chemical industry there is to be found a comparable example of the use of chemicals in the tonnages consumed by the water works industry and in the dilutions employed by it. The chemical reactions, not only of coagulation but of softening as well, are carried out in extremely low concentrations, and it is a tribute to the ingenuity, resourcefulness and scientific ability of the water works man that they are so successfully employed under these unusual conditions.

R & D

Decimal Equivalents
of 8ths, 16ths, 32ds, and 64ths of an Inch

8ths				
1/8 = .125	9/16 = .5625	17/32 = .53125	9/64 = .140625	37/64 = .578125
1/4 = .250	11/16 = .6875	19/32 = .59375	11/64 = .171875	39/64 = .609375
3/8 = .375	13/16 = .8125	21/32 = .65625	13/64 = .203125	41/64 = .640625
1/2 = .500	15/16 = .9375	23/32 = .71875	15/64 = .234375	43/64 = .671875
5/8 = .625		25/32 = .78125	17/64 = .265625	45/64 = .703125
3/4 = .750	32ds	27/32 = .84375	19/64 = .296875	47/64 = .734375
7/8 = .875	1/32 = .03125	29/32 = .90625	21/64 = .328125	49/64 = .765625
	3/32 = .09375	31/32 = .96875	23/64 = .359375	51/64 = .796875
16ths	5/32 = .15625		25/64 = .390625	53/64 = .828125
1/16 = .0625	7/32 = .21875	64ths	27/64 = .421875	55/64 = .859375
3/16 = .1875	9/32 = .28125	1/64 = .015625	29/64 = .453125	57/64 = .890625
5/16 = .3125	11/32 = .34375	3/64 = .046875	31/64 = .484375	59/64 = .921875
7/16 = .4375	13/32 = .40625	5/64 = .078125	33/64 = .515625	61/64 = .953125
	15/32 = .46875	7/64 = .109375	35/64 = .546875	63/64 = .984375

CORROSION CONTROL*

WHEN METALLIC structures, pipe or other water and sewage works equipment go into solution, the action is known as corrosion. Corrosive action in the presence of moisture, depends on pH, temperature, oxygen, characteristic of the metal, etc.

Effects of Corrosion

Corrosion in water systems may result in tuberculation (with accompanying loss in carrying capacity) and in disintegration of pipe, leaks in lines, clogging, deterioration of meter parts and leaks in domestic water heaters. Corrosion may also cause water to become turbid, colored, or to have an undesirable taste. Lead, or zinc dissolved may cause water to be toxic and copper and iron in water supplies will stain household fixtures.

In sewage works, unfavorable corrosion effects are noted in mechanical equipment as well as in the deterioration of metal structures of all kinds.

Fundamentals of Corrosion

No metal is stable in the presence of moisture and oxygen. All metals tend to be converted to oxides, hydroxides or salts of the metal and therefore to be destroyed. Corrosion is an electro-chemical process. Moore, et al, explain the mechanism as taking place in four steps: 1. Anodic Reaction, 2. Cathodic Reaction, 3. Depolarization, and 4. Reactions of the Metal Ions.—1. A metal ion goes into solution with an alectron going to the main mass of metal; 2. The metal mass gives up electrons to react with hydrogen ions in the water to form hydrogen gas; 3. hydrogen is prevented from accumulating on the metal surface by reacting with oxygen dissolved in the water; 4. The metal ions released to the water react with ions or oxygen in the water to form soluble or insoluble products, oxides, hydroxides, carbonates, etc.

If one of these steps can be prevented or controlled then corrosion can be prevented or controlled.

CORROSION CONTROL

Principal methods by which corrosion is reduced, if not prevented, are: 1. Proper selection of material; 2. Use of protective coatings; 3. Treatment of the water.

Materials

The selection of material (metallic or non-metallic) will give consideration to characteristics of the material and its resistance to the dissolving effect of water. Non-metallic materials include wood, concrete, asbestos-cement, tile and plastics.

Wood is infrequently used. Reinforced concrete is used for tanks, other structures and for sewers; prestressed concrete for water transmission mains and elevated storage tanks. Asbestos-cement is used as siding for buildings, for shear gates in sewage conduits, and for water and sewer pipe. Neither concrete nor asbestos-cement will withstand acid waters.

Tile is used for sewers, and filter bottoms in both water and sewage plants. Plastics are corrosion resistant but have a temperature limitation.

Metals commonly and widely used are cast iron for water mains; steel for structural members of buildings and for mechanisms and mechanical equipment of all kinds.

Copper pipe is used for house piping but it should be tin lined if the water is soft and contains carbon dioxide in appreciable amount. Red brass (85 percent copper) is resistant to corrosion, but if the copper content is less than 60 percent, zinc will be dissolved out in soft waters. Lead pipe can be used in hard waters, but not in soft. Aluminum is used mostly for decorative purposes, stairs, hand rails, gratings, etc.

Special corrosion resistant alloys are used for specific purposes, particularly in the handling of chemical solutions, or in sewage plants where silicon bronze is used for valves, sluice gates, etc. Rubber and hard rubber, glass or plastic are used for handling moist chlorine or chlorine in solution and other chemicals. Dry liquid chlorine is handled in black iron, steel or copper. Ceramics are used for tanks for corrosive chemical solutions.

Protective Coating

Construction of pipes and equipment of completely non-corrosive materials is generally too expensive, or the material does not have desired strength, etc. Instead materials subject to corrosion are coated with another material that is non-corrosive or at least corrosion resistant.

Protective coatings may be non-metallic or metallic. Non-metallic coatings include paints; asphalts or bitumastic, rubber, plastic, glass, and cement linings. Asphaltic and cement linings are used in water mains; rubber, plastic and glass in small pipes or tanks handling corrosive chemical solutions. Specially developed paints are applied to mechanisms and structures for water and sewage works. The old advertizing slogan, "Save the surface and you save all" is applicable in water and sewage works.

Metallic coatings are used and are useful in certain applications. Best known perhaps are zinc and lead. Galvanized iron is resistant to atmospheric corrosion but it is seldom used for contact with liquid. Copper, nickel, chromium, etc. are effective coatings for some uses, with the coating being applied by electroplating. Aluminum coatings are also used. Creation of a corrosion resistent surface of the metal itself by oxide or phosphate layer is done by Parkerizing, bonderizing or anodizing. Natural protection is afforded by the deposition of protective layers as calcium carbonate or silicates, or oxides on aluminum, etc.

Treatment

According to Moore, et al., corrosion may be prevented or reduced by treatment of the water, including pH adjustment, deposition of mineral film such as calcium carbonate, or phosphates, addition of organic corrosion inhibitors, adding agents to make the metal passive, and removal of dissolved oxygen and carbon dioxide.

Since corrosion is an electro-chemical process it can proceed under the influence of galvanic action where unlike metals are close together; stray electric currents will also cause corrosion. Best preventive for these types of corosion, is cathodic protection whereby a definite current is impressed on the metal to prevent the metal tendency to dissolve. Cathodic protection systems have been quite effective in preventing corrosion in elevated steel storage tanks, cast iron and steel pipe lines, and in sewage plant equipment.

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* Based on material in "Fundamentals of Corrosion and Its Mitigation" by Moore, Sears, and Rubin; Wat. & Sew. Wks. 100 R-102 (1953)

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Mechanism of Water Pipe Corrosion

By ROLF ELIASSON and JAMES C. LAMB III

Mr. Eliasson is Prof. of San. Eng., and Mr. Lamb is a Research Asst., both with Mass. Inst. of Technology, Cambridge, Mass.

IRON occurs in nature in the form of an oxide or hydroxide, and the metal is produced through reduction of the ore. Corrosion may be considered as the reverse of this process, as iron is unstable in a corrosive environment and tends to revert to the more stable oxides.

The tendency of a metal to go into solution, or to corrode, is indicated by its electrode potential in that solution. In order to provide a standard basis for comparing the solution tendencies of the various metals, a metal ion "activity" of 1 mole per 1,000 g of water and a temperature of 25°C have been assumed in the preparation of the electromotive force series. In the abbreviated emf series presented in Table 1, the potential of hydrogen is taken as zero and all other potentials are referred to this value[1,2]. The metals are listed in order of decreasing solution tendency (increasing nobility of potential). The potential, E, of a metal under other conditions of temperature and metal ion activity may be found through the use of the Nernst equation:

$$E = E_0 - \frac{RT}{nF} \log_e (M^{++})$$

in which M^{++} is the metal ion activity in solution (gram-moles of metal per 1,000 g of water, multiplied by the activity coefficient); R is the gas constant, in joules; T is the absolute temperature (Kelvin); n is the number of electrons participating in the reaction; E_0 is the potential, in volts, of the metal at 25°C with unit metal ion activity; and F equals 1 faraday equals 96,500 coulombs per equivalent.

Table 1

ELECTROMOTIVE FORCE SERIES*

Electrode Reaction	Standard Electrode Potential (E_0), 25°C, v
$Ca = Ca^{++} + 2e^-$	— 2.87
$Na = Na^+ + e^-$	— 2.712
$Mg = Mg^{++} + 2e^-$	— 2.34
$Al = Al^{+++} + 3e^-$	— 1.67
$Zn = Zn^{++} + 2e^-$	— 0.762
$Cr = Cr^{+++} + 3e^-$	— 0.52
$Fe = Fe^{++} + 2e^-$	— 0.440
$Ni = Ni^{++} + 2e^-$	— 0.250
$Sn = Sn^{++} + 2e^-$	— 0.136
$Pb = Pb^{++} + 2e^-$	— 0.126
$H_2 = 2H^+ + 2e^-$	0.000
$Cu = Cu^{++} + 2e^-$	0.345
$Ag = Ag^+ + e^-$	0.800
$Pt = Pt^{++} + 2e^-$	1.2

*Signs of potential employed by the American Chemical Society are opposite to those of this table.

At 25°C, this equation may be expressed:

$$E = E_0 - \frac{0.059}{n} \log_{10} (M^{++})$$

There has been a tendency to use the emf series as though it were inflexible, each metal displacing from solution all metals below it in the series. This condition is usually true for metals widely separated in the series, but it should not be assumed to obtain in all instances. Changes in the potentials of metals in dilute solutions, such as are normally encountered in water works practice, may result in radical changes in the order of potentials given in the emf series.

Such a change occurs, for example, in the iron-zinc system. Zinc is normally anodic (more active potential) to iron, and is used in many piping systems as a sacrificial protective coating for iron. In fresh water with a temperature higher than 150°F, however, it becomes cathodic (more noble potential) to iron and is no longer sacrificially protective[3]. The effective potential of a metal also may be varied by reactions with elements in a given environment. It is evident that the emf series, calculated for unit metal activity, cannot be applied directly to determine the potential of a metal under the conditions normally found in water works practice.

Table 2

GALVANIC SERIES OF METALS AND ALLOYS

Corroded end (anodic or least noble)	Magnesium
	Zinc
	Aluminum 28*
	Steel or iron
	Cast iron
	Lead
	Tin
	Brasses
	Copper
	Bronzes
	Chromium-iron (passive)
	Silver
Protected end (cathodic or most noble)	Graphite
	Gold
	Platinum

*"Commercial pure" aluminum.

A galvanic series is one in which metals are arranged in their usual electro-potential sequence in a given environment. Therefore, although there is only one emf series, there may be many galvanic series, each applying to a given set of environmental conditions. In a galvanic series, like the abbreviated example in Table 2, actual potential values are not given, as these vary widely with different environmental conditions[1,2]. Metals that are grouped together in a gal-

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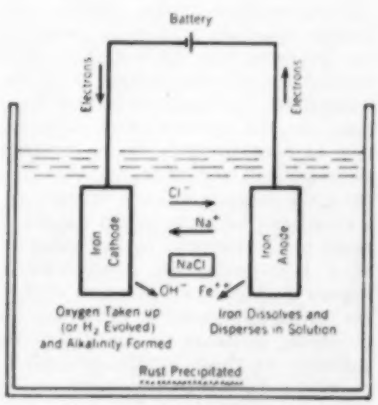

Fig. 1. Impressed-Current Cell
The current flow between the electrodes results in a loss of metal from the anode.

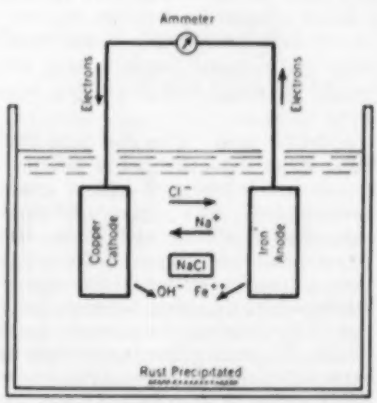

Fig. 2. Galvanic Cell
The reactions at the electrodes are identical with those in the impressed-current cell, but the current flow is due to the difference in the electrode potentials rather than to an external source.

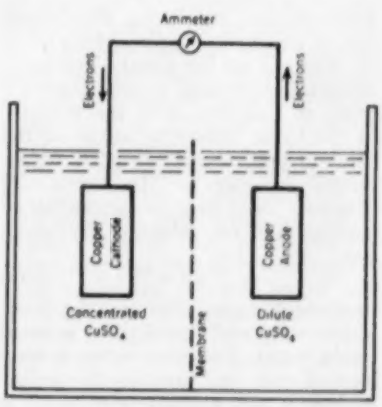

Fig. 3. Concentration Cell
In this type of corrosion cell, the difference in electrode potentials results from the difference in metal ion concentrations in the solutions.

vanic series have little tendency to form galvanic cells, while metals that are widely separated have a great tendency to form such cells when used together.

Corrosion Cells

Many kinds of electrolytic cells are capable of causing the corrosion of metal, but those most commonly encountered in practice may be divided into a few basic types: impressed-current cells, galvanic or differential-metal cells, concentration cells, differential-aeration cells, differential-temperature cells, and differential-stress cells.

Impressed-current cells. It is well known that, in an impressed-current cell (Fig. 1), the current flow between the electrodes results in a loss of metal from the anode in accordance with one of the following reactions, depending upon the current density:

$$Fe^0 \rightarrow Fe^{++} + 2e \quad \ldots\ldots (1)$$

or:

$$Fe^0 \rightarrow Fe^{+++} + 3e \quad \ldots\ldots (2)$$

The rate at which the metal passes into solution is directly related to the rate of current flow between the electrodes. Faraday's law states that the passage of 1 faraday of electricity (96,500 ampsec or coulombs) through an electrolytic solution produces one chemical equivalent of some chemical change at each electrode. Therefore, the passage of 1 faraday of electricity between the electrodes in Fig. 1 must cause one chemical equivalent if iron to enter solution from the anode.

One chemical equivalent of change is also produced at the cathode for each faraday of electricity passing through the solution. The primary reaction at this electrode involves the removal of electrons from the metal through neutralization of hydrogen ions in solution:

$$2H^+ + 2e \rightarrow 2H^0 \quad \ldots\ldots (3)$$

This reaction results in the formation of atomic hydrogen, which tends to plate out on the metal. The layer of atomic hydrogen on this electrode tends to interfere with the transfer of electrons from the metal to the solution and, therefore, must be removed in order for the reaction to proceed. This may be accomplished through the formation of hydrogen gas:

$$2H \rightarrow H_2\uparrow \quad \ldots\ldots (4)$$

or through reaction between the atomic hydrogen and chemicals in solution in the water. The most common reaction of this type involves the atomic hydrogen and oxygen in solution in the water:

$$4H + 2O_2 \rightarrow 2H_2O \quad \ldots\ldots (5)$$

Other possible types of reactions between hydrogen and the oxygen in solution have been suggested [1-4]. The neutralization of hydrogen ions in the solution at the cathode results in the production of alkaline conditions in the vicinity of this electrode. The metal ions or salts entering solution from the anode react with alkalinity and oxygen in solution to form iron oxides, known as rust. These oxides may be formed in the vicinity of the anode or cathode, or in a location remote from either electrode.

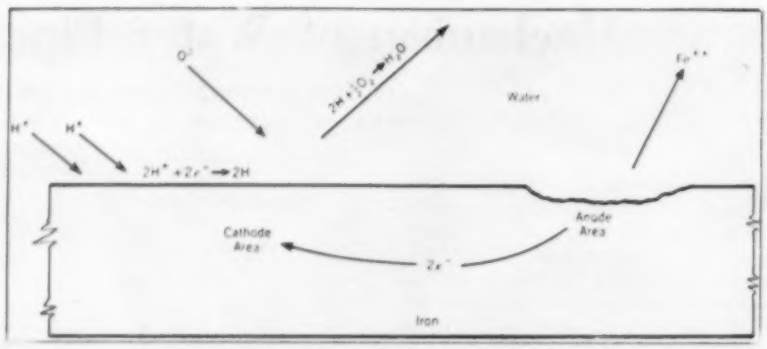

Fig. 4. Corrosion Cell on Surface of Submerged Iron

The surface of a large section of metal may be covered by many such cells, the electrode reactions of which are similar to those discussed previously.

The potential of a metal in water may be changed through the application of impressed currents, causing an increase or decrease in the rate of corrosion of the metal, depending upon the direction and magnitude of the applied emf[5]. This phenomenon can be observed in the external corrosion of pipelines by stray currents and in the cathodic protection of pipeline exteriors and other structures by applied emf.

The corrosion of iron in water usually occurs in the absence of impressed currents. Whitney[6] showed that the corrosion of iron in water is electrochemical in nature, and Evans and Hoar[8] demonstrated that there is a direct relationship between the current flowing between anodes and cathodes on a metal surface and the weight of metal lost from that surface.

Galvanic cells. The emf and galvanic series show that, when different metals are introduced into a given environment, they have different tendencies to corrode, and display different potentials. Figure 2 illustrates such a situation, with iron and copper immersed in the same aqueous solution. Examination of a galvanic series (Table 2) reveals that copper may be expected to display more noble (cathodic) potential than iron. If the two metals are connected electrically, the difference in potentials between the iron and copper results in a flow of current between the electrodes. This may be demonstrated by connecting the two electrodes through an ammeter, as shown, and measuring the galvanic current flow.

In the cell shown in Fig. 2, the iron has the greater tendency to pass into solution, leaving electrons at the metal surface. These electrons pass through the metallic portion of the circuit to the copper electrode and are transferred from the metal to the solution by neutralization of hydrogen ions in the solution. The atomic hydrogen is removed from the copper through the formation of hydrogen gas or reaction with oxygen in solution. In this cell, the iron serves as the anode (electrode at which takes place), while the copper functions as the cathode (electrode at which reduction takes place). The current flow that accompanies the loss of metal from the anode is generated by the difference in potentials between the electrodes in the galvanic cell rather than by an external source of emf as in the impressed-current cell. Therefore, the galvanic cell in Fig. 2 can be considered—and, in fact, is—nothing more or less than a battery. The reactions taking place at each electrode are identical with those described above for the impressed-current cell.

Concentration cells. From the Nernst equation previously given, it can be seen that the potential of a metal in a solution varies with the concentration of its ions in that solution. As the concentration of metal ions in solution increases, it becomes more difficult for additional metal to enter the solution as ions. Therefore, a metal can be expected to display a more noble potential in the presence of a high metal ion concentration. Figure 3 shows two identical copper electrodes immersed in solutions of different concentrations of copper sulfate. As these electrodes are exposed to different concentrations of copper ions, they have different potentials. The electrode in the more concentrated solution has a more noble

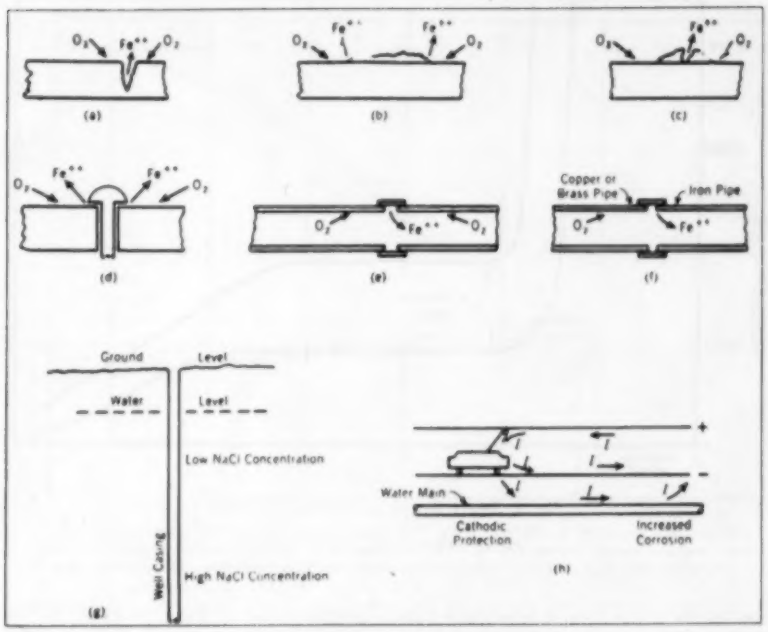

Fig. 5. Typical Corrosion Cells Found in Practice

Key: (a) pit or depression; (b) mill scale or corrosion products; (c) biological growth; (d) rivet or bolt; (e) pipe coupling (same metals); (f) pipe coupling (dissimilar metals); g) well casing in water with varying salt content; (h) stray-current corrosion. The first five are examples of differential-aeration cells; the remaining three illustrate, respectively, galvanic, concentration, and impressed-current cells.

potential and acts as the cathode in the corrosion cell, while the other electrode functions as the anode.

The potential of a metal in solution is affected by the concentration of ions other than metal ions. For example, a concentration cell similar to the one in Fig. 3 can be prepared by using two sodium chloride solutions of different strength. This effect can also be observed with metals immersed in solutions of different substances (acids, bases, salts, or gases).

Differential-aeration cells. A differential-aeration cell is a special type of concentration cell which is of particular significance in the water works field. The rate of the chemical reaction between the oxygen in solution and the hydrogen atoms on the metal depends upon the rate of access of oxygen to the metal surface. Therefore, if one electrode of a corrosion cell receives oxygen at a higher rate than the other, the polarizing layer of hydrogen on this electrode is removed more rapidly. The rapid removal of hydrogen facilitates the transfer of electrons from the metal to the solution at that point, and this area of the metal becomes the cathode of the corrosion cell. The electrode that receives less oxygen becomes the anode of the differential-aeration cell. This electrode suffers an increase in corrosion rate owing to the increased rate of depolarization at the cathode. The significance of this type of corrosion cell in water works practice will be discussed more fully later.

Differential-temperature and differential-stress cells. Differences in temperatures and stresses of metals may result in the formation of corrosion cells. These types of cells may be important in initiating corrosion, but their effects are usually obscured by other, more significant kinds of corrosion cells. Therefore, on a long-term basis, differential-temperature and differential-stress cells are of relatively little importance, under the conditions usually found in water works.

Formation of Corrosion Cells

For the sake of clarity, the electrodes in the cells considered in the preceding section were assumed to be individual pieces of metal. The corrosion of a single submerged metallic object results from the formation of anodes and cathodes on the surface of the metal. Figure 4 shows, schematically, a typical corrosion cell on the surface of a submerged sheet of iron. The anode and cathode of this cell are short circuited by the body of metal. It will be noted that the cell and the electrode reactions shown in Fig. 4 do not differ basically from those which have been discussed previously. The surface of a large section of metal might be covered by many such corrosion cells. The presence of local anodes and cathodes on the surfaces of corroding metals has been demonstrated, and it has been shown that the amount of current flowing between the electrodes and the weight of metal lost can be definitely correlated[6,7].

The formation of a corrosion cell on the surface of a metal may be due to differences in metal composition, electrolyte concentration cells, or differential-aeration, -temperature, or -stress cells. Figure 5 shows a few typical examples of how such cells may be formed in practice. The first five (Fig. 5a-5e) are examples of differential-aeration cells. In each instance, the portion of the metal that has freer access to oxygen acts as the cathode in the corrosion cell, while the portion shielded from oxygen becomes the anode.

Figure 5f shows a galvanic cell caused by connecting pipes made of different metals. Copper and brass are cathodic to iron, and, therefore, the iron pipe corrodes while the copper or brass pipe acts as the cathode in the corrosion cell. Figure 5g shows conditions under which an electrolyte concentration cell may be encountered in the external corrosion of pipelines passing through soils or waters that vary widely in chemical characteristics.

Finally, Fig. 5h illustrates a common example of corrosion by impressed current. If the water main may become part of the return circuit to a power plant furnishing electricity for a streetcar system, the portion of the pipe where the current passes from pipe to ground suffers an increase in corrosion rate. The corrosion rate of that portion of pipe at which no interchange of current takes place between pipe and ground is not affected, and the internal corrosion of the pipeline is likewise unaffected.

The types of cells capable of causing corrosion have been discussed individually, but it must be stressed that two or more varieties may tend to occur simultaneously. For example, the concentration of metal ions under a tubercle (Fig. 5c) could be expected to be higher than in the water surrounding the tubercle. Therefore, consideration of the relative concentrations of metal ions would indicate a tendency toward the formation of a corrosion cell in which the area of metal under the tubercle would act as the cathode. The differential-aeration cell formed by the action of the tubercle in shielding a portion of the metal from oxygen tends, however, to result in the formation of a cell in which the area of metal outside the tubercle acts as the cathode and the area under the tubercle serves as the anode.

Rate of Corrosion

It has been pointed out that the rate of corrosion of a metal in aqueous solution is a function of the rate of current flow between anodes and cathodes on the surface of the metal. The reactions taking place in a corrosion cell have been presented in the preceding sections. It is evident that, in order for corrosion to take place (Reaction 1), the electrons left on the metal by this reaction must be removed (Reactions 3-5). Otherwise, a counter, or back, emf will be built up on the metal, and the corrosion will be stifled. Therefore, in a corrosion cell, the anode and cathode reactions must proceed at the same rate. Any reduction in the rate of the reaction at either electrode must result in a corresponding reduction in the rate of current flow between the electrodes and, hence, in the rate of corrosion of the metal. In practice, the rate of corrosion may be controlled by reducing the rate of the anode reaction, the cathode reaction, or both.

The removal of the polarizing layer of hydrogen from the cathode may be accomplished through hydrogen evolution (Reaction 4) or through oxygen depolarization (Reaction 5). It has been shown by past investigators that, in neutral or mildly alkaline waters, corrosion with evolution of hydrogen at the cathode is negligible, although the relative positions of iron and hydrogen in the emf series might lead to the supposition that the corrosion of iron should be accompanied by continuous evolution of hydrogen. The explanation is that resistance or "overvoltage" must be surmounted before hydrogen can be evolved as a gas from a metal surface. In neutral or mildly alkaline waters, the overvoltage is too high to allow the escape of appreciable amounts of hydrogen gas from iron cathodes. As the pH of a water decreases below a value of approximately 4.0, the hydrogen ion concentration is increased to such an extent that hydrogen evolution is greatly facilitated, and the formation of this gas becomes a major cathodic reaction.

Because the waters encountered in municipal and industrial systems are generally neutral or slightly alkaline, the amount of corrosion due to hydrogen evolution is of minor significance —approximately 3 per cent, according to Speller[3]. Therefore, the primary cathodic reaction in these systems must be the removal of hydrogen by reaction with oxygen in solution in the water (Reaction 5). The anode reaction rate is much more rapid than the depolarization reaction rate at the cathode[3]. As both reactions must proceed at the same rate, it is evident that the rate of corrosion of iron in natural waters is controlled by the rate of oxygen supply to the cathodes of the corrosion cells. The latter rate is influenced by the concentration of oxygen in solution, the rate of flow and turbulence of the water, and the presence of films of oxides or inhibitors on the metal surface. Within the range of oxygen concentrations normally found in municipal and industrial waters, the rate of corrosion increases directly with the rise in oxygen concentration.

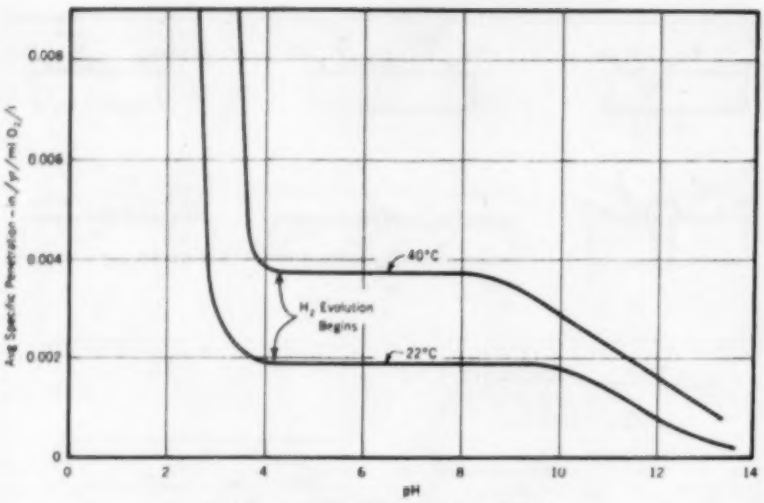

Fig. 6. Effect on pH on Corrosion of Steel

In the pH range 4-10, the corrosion rate depends on the rate of oxygen supplied to the metal surface. Above pH 10, the formation of a layer of corrosion products leads to passivity. Below pH 4, hydrogen evolution becomes a major cathodic reaction.

Uhlig[4] has stated that: "All iron and steel, regardless of minor variations of composition or structure, corrode at the same rate in natural waters." This fact is of great significance to the water works industry, which uses many types of iron and steel pipes for various reasons, some realistic and others not.

The formation of films on the surfaces of metals has a significant effect on their corroding characteristics. The films formed on metals may include layers of hydrogen or oxygen, films formed by chemical reaction between corrosion products and elements of the corrosive environment, and films formed by inhibiting agents added to the corrosive medium. Film formation may occur preferentially at either anodes or cathodes of corrosion cells, or over the entire surface of the metal. Films on the cathodes of corrosion cells may interfere with the transfer of electrons from the metal to the solution. The formation of these films may result from the electrodeposition of positively charged ions or colloidal particles on the cathode, from sorption of chemicals on the metal surface, or from the reaction of some chemical in solution with the alkalinity produced at this electrode, resulting in the formation of an insoluble precipitate on the metal.

Anode films may be formed through electrodeposition of negatively charged ions or colloidal particles on this electrode, through sorption of chemicals on the metal surface, or through the production of an insoluble precipitate by reaction between the iron entering solution and chemicals in solution. The formation of an anode film may result in the effective separation of the metal from the water at the anode, stifling the anode reaction.

Under certain conditions, film formation on a metal may be accompanied by a radical change in the potential of that metal to a more noble value. When a metal undergoes a sharp reduction in corrosion rate, accompanied by a shift in potential to a more noble value, it is said to be "passive."

Figure 6 shows the effect of the pH of the water on the corrosion rate of mild steel in the absence of the formation of protective coatings[5]. The rate is essentially constant in the range of pH 4—10 at 22°C. In this range, the predominant cathodic reaction is oxygen depolarization, and the corrosion rate is determined by the rate of supply of oxygen to the metal surface. As the pH of the water is decreased below 4, hydrogen evolution becomes a major cathodic reaction. The increased corrosion rate at low pH values can be attributed to increased hydrogen ion concentration in the solution and the dissolving action of the water on any protective

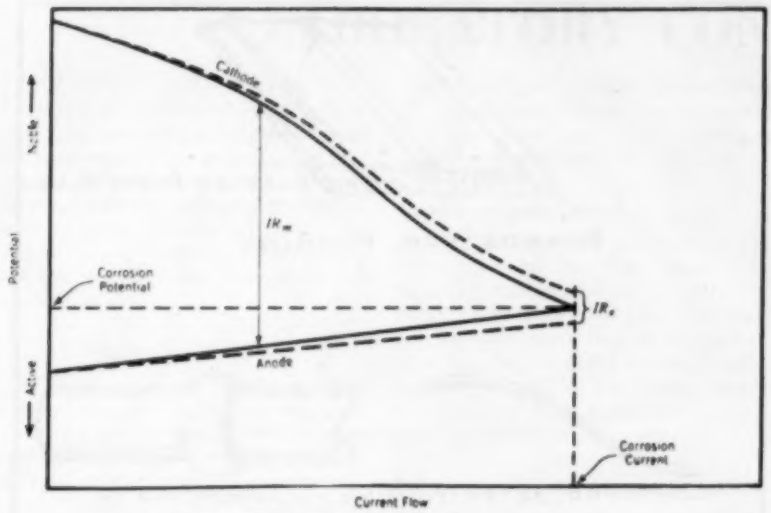

Fig. 7. Typical Polarization Curves

The solid lines represent the curves that would be obtained if the electrode potentials were measured against a "remote" reference cell; the broken lines indicate the curves resulting from the use of "probe" electrodes, located close to the respective corrosion cell electrodes.

layers of corrosion products on the metal. As the pH is increased above 10, a protective layer of corrosion products is formed on the metal, or the surface reaction rate of the iron becomes lower, resulting in passivity of the metal and a decrease in the corrosion rate. The chemicals present in natural waters may have a great effect upon the shapes of the curves in Fig. 6, through reaction with corrosion products and formation of protective coatings.

Polarization

In a corrosion cell, the driving force for the electrical current flow between the electrodes is the difference in potential between the anode and the cathode of the cell. From Kirchoff's second law:

$$\Sigma \text{emf} = \Sigma IR$$

or:

$$E_c - E_a = IR_e + IR_m$$

in which R_e is the resistance of the electrolytic portion of the circuit; R_m is the resistance of the metallic portion of the circuit; E_c is the effective (polarized) potential of the cathode; E_a is the effective (polarized) potential of the anode; and I is the current flow between the electrodes.

The potentials of anodes and cathodes in corrosion cells may vary with the current flow through the cells. This effect is known as polarization and is comparable to friction in a mechanical or hydraulic system. As the current flow through a corrosion cell increases, the potentials of the anode and cathode tend to approach a common value. Polarization of both electrodes would result in a shift in the anode potential in the cathodic direction and a shift in the cathode potential in the anodic direction. Therefore, the potential difference between the electrodes in a corrosion cell through which current is flowing is usually less than the difference in the open-circuit potentials, or potentials of the electrodes with no current flowing. An increase in the degree of polarization of either electrode results in a decrease in the potential difference between the electrodes (or driving force for the corrosion process) and, thus, in a decrease in the rate of current flow in the cell.

The polarizing characteristics of separate anodes and cathodes under a given set of conditions may be determined by varying the rate of current flow between the electrodes (by varying R_m) and measuring the potential of each electrode against that of a standard reference cell. In Fig. 7 is shown a typical pair of polarization curves, indicating the potentials of the anode and cathode of a corrosion cell at various values of current flow between the electrodes. The points at which the curves intercept the ordinate axis represent the open-circuit potentials of the electrodes (no current flowing in the corrosion cell). The intersection of the curves gives the corrosion potential and the corrosion current with the electrodes short-circuited, which is usually the situation in practice. The curves represented by the solid lines are separated by a distance equal to IR_m. These are the curves that would be obtained by measuring the potentials of the electrodes against a "remote" reference cell, or a reference cell located midway between the electrodes. The broken lines in Fig. 7 are those which would be obtained through the use of probe electrodes, located in the immediate vicinity of the respective corrosion cell electrodes. These curves are separated by a distance equal to $IR_e + IR_m$.

It has been stated that the rate of corrosion may be controlled by the rate of the cathode reaction, the anode reaction, or both. Altogether, four types of control are possible in corrosion cells. These are illustrated in Fig. 8. Figure 8a represents the limiting case of "resistance control," in which the current flow between the electrodes has no effect on the potential of either of them; the current flow in the corrosion cell is limited by the IR_e and IR_m of the system, and the potential of each electrode remains constant at the value of the open-circuit potential for that electrode. This situation would never occur in water works practice. Figure 8b represents the case in which the current flow in the corrosion cell is limited by the polarization (change in potential with current flow) of the cathode. In this instance, the corrosion is said to be under "cathodic control." Figures 8c and 8d show polarization curves that might be obtained when the rate of corrosion is controlled by polarization of the anode ("anodic control") or of both electrodes ("mixed control").

It has been pointed out that, in aqueous solutions with no inhibitors present, the anode reaction rate in the corrosion of iron is very much faster than the depolarization reaction rate at the cathode. In neutral or slightly alkaline waters, the rate of corrosion is almost completely governed by the rate of supply of oxygen to the cathode. Therefore, in most municipal and industrial water systems, the corrosion is under primarily cathodic control, as illustrated in Fig. 8b. The rate of corrosion is governed by the degree of polarization of the cathode.

Distribution of Corrosion

The factors affecting the overall rate of corrosion of iron in water have been discussed. Other factors of equal significance are those which influence the distribution of corrosion occurring; the corrosion may take place uniformly over the entire metal surface or be localized, with the entire loss of metal confined to a relatively small area. The life of a metallic structure in water is determined, to a large extent, by the rate of penetration of the structure by corrosion. Localized attack may lead to rapid failure of the structure, although a relatively small proportion of the metal has been lost to solution.

board or plank already placed and space the two top boards the width of the annular space to be filled and have the two top boards thick enough to be two-thirds the depth of the socket of the pipe, or space your top boards at a distance equal to two-thirds the depth of the socket and as thick as the width, either way will do.

Put a good coat of wash (composed of whitening and water creamy in consistency) with a brush between the space of the boards. This is to keep the compound from sticking to the boards. Put a plug of trench clay in the boards at each end or at a distance equal to the circumference of the pipe or pour several lengths at one pour.

Pour the compound steadily backwards and forwards into the opening, leave it ten minutes to properly set. When one side board is taken away a compound strip, rubber like, has been made.

In warm weather this will be found quite flexible; in cold weather the rings can be kept flexible by laying on a board near the heating pot. Fit it into the joint space and caulk the joint with a piece of hardwood or caulking tool, then cement the balance of the annular space. This will give a waterproof and root-proof joint, with a minimum of labor.

In very wet trenches it is suggested that after caulking in the first ring a second ring be caulked in and the cement eliminated.

The importance of laying and jointing sewer pipes has been recognized by the government of the Province of Ontario, which last year passed a bill enabling all towns and cities to license sewer and drain layers. Men doing this work should be classed as skilled labor. They should be made conversant with the engineers' specifications and the importance of proper laying and jointing should be conveyed to them personally by the engineer or inspector.

They should be made to feel that the importance of their work is appreciated and confidence is placed in their ability to do their best under sometimes very difficult circumstances.

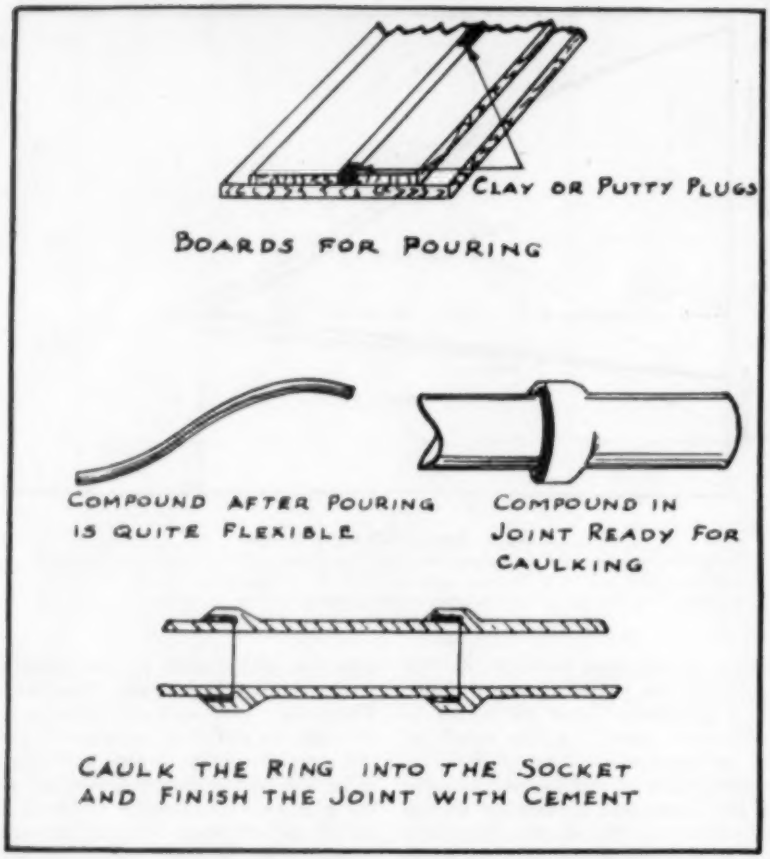
CLAY OR PUTTY PLUGS
BOARDS FOR POURING
COMPOUND AFTER POURING IS QUITE FLEXIBLE
COMPOUND IN JOINT READY FOR CAULKING
CAULK THE RING INTO THE SOCKET AND FINISH THE JOINT WITH CEMENT

Fig. 4. Combination Compound and Cement Joint

Definite and complete specifications by the engineer and co-operation of the contractor and his pipe layer will eliminate root trouble and infiltration.

CARRYING CAPACITY OF SEWER PIPE—GALLONS PER MINUTE

(Based on "Hydraulic Tables" by Williams & Hazen)

Size, Inches	1" Fall in 100 Feet	2" Fall in 100 Feet	3" Fall in 100 Feet	6" Fall in 100 Feet	9" Fall in 100 Feet	12" Fall in 100 Feet	24" Fall in 100 Feet	36" Fall in 100 Feet
4	....	.....	.....	.....	86	102	149	186
6	....	.....	.....	204	256	297	269	534
8	....	.....	.....	437	539	632	921	1143
9	....	.....	.....	601	749	876	1272	1580
10	....	.....	537	781	974	1138	1653	2055
12	....	730	869	1264	1571	1835	2695	3345
15	....	1242	1556	2275	2835	3300	4790	5950
18	....	2030	2510	3670	4580	5340	7760	9665
24	2985	4325	5390	7810	9740	11380	16530	20550
27	4040	5875	7325	10690	13270	15520	22530	27850
30	5340	7760	8670	14080	17500	20450	29750	37150
36	8740	12600	15640	22700	28350	33000	47900	59500

LABORATORY CONTROL

EVERY WATER and sewage plant should have some laboratory facilities. The size of the laboratory and the equipment it contains should be determined according to the size of the plant and the extent of treatment. Both of these factors will affect the frequency of sampling and testing and the number and complexity of tests to be made.

Water Treatment

In most states, it is the general practice to have water samples analyzed by the state health laboratory at least once a month and for the water plant to submit a monthly report of results obtained by routine testing at the plant. Many state health departments stipulate the frequency and kind of tests to be made on a routine basis.

Chlorination

Where chlorination is the only treatment practiced, testing equipment is required to determine the amount and kind of chlorine residuals. Handy colorimetric test kits are available. This same equipment is useful in larger plants, as well.

Coagulation, Sedimentation, Filtration

Equipment for determining proper coagulation dosage is essential to good control of the process. The coagulation "jar test," made using a multiple laboratory stirrer, is the best control test. Waters requiring coagulation usually are tested for pH alkalinity, turbidity, color and taste and odor. Alkalinity requires a minimum of laboratory apparatus and pH can be determined colorimetrically with dyes. For pH, however, it is preferable to use an electric pH meter and larger laboratories should be so equipped. Turbidity tests require a turbidimeter (either candle or electric). Color tests can be made in a colorimeter, one type of which utilizes colored glass discs and the other which uses Nessler tubes containing standard color solutions.

Bacteriological Control

Where the water supply is taken from a surface supply, particularly in a flashy stream, or one subject to human pollution, it is desirable to make bacteriological tests on both raw and finished water. The most common tests are the bacteria plate count, and the presumptive or confirmed test for coliform organisms. Both require a refrigerator for keeping prepared media and a constant temperature 37°C incubator. Some special laboratory glassware and a bacteria colony counting device are also required.

Taste and Odor Control

Most of the taste and odor problems in water supplies come from algæ. Treatment of algæ in reservoirs, particularly with copper sulfate, must be controlled according to the type of algæ present. In order to identify the algæ organisms, a laboratory should be equipped with a microscope and pertinent equipment.

Softening

In addition to pH and alkalinity tests in softening, hardness determinations should be made. In large softening plants more complete chemical analyses are made to determine calcium, magnesium, sulfates, chlorides, etc. Also, the laboratory is usually equipped to analyze the chemicals purchased. A fairly well equipped laboratory is required.

Sewage Treatment

Many state health departments require sewage plants to submit monthly records of routine tests and in some cases stipulate the tests to be made according to the size and type of treatment plant.

Primary Treatment and Chlorination

In the smallest plants, where only primary treatment is used, such as Imhoff Tank plants, settleable solids by volume are required, using the Imhoff cone test. In some small plants, the methylene blue stability test is also made. When chlorination is also used, residual chlorine tests should be made but the type of residual is not important.

In larger plants utilizing primary treatment only, the tests made will include suspended solids, B.O.D. and possibly pH and alkalinity. If gas from separate digestion is collected and used, gas analyses may be made. Where chlorination is important to the control bacterial pollution of the receiving waters, bacteriological tests must also be made as well as chlorine demand tests and chlorine residual tests. Special tests on settleable solids by weight may also be made.

All of these tests require a certain amount of laboratory apparatus and glassware for specific purposes. In addition, B.O.D. tests require a constant temperature 20°C incubator. Solids determinations require an analytical balance, steam or water bath, drying oven and muffle. Gas analyses require special analytical apparatus, but pH, alkalinity and bacteria require the same equipment as used in the medium and large sized water works laboratories. Chlorination control uses the same equipment as used in water works.

Secondary Treatment

If trickling filters are used, B.O.D. tests are required. The activated sludge process likewise requires the B.O.D. test and control tests using dissolved oxygen determinations, sludge volume and density determinations. None of these require any additional types of equipment to that already outlined.

Sludge Dewatering

When sludge is digested, some control tests are made on the raw and digested sludge. Usually these are total solid matter, volatile matter, pH and alkalinity. The same equipment is used as for testing raw sewage. If the sludge is dewatered on vacuum filters, control tests are necessary to determine the proper dosage of chemicals. For this control, pH, alkalinity and other special tests may be used, but no special apparatus is required except a pH meter.

If the dewatered sludge is dried or incinerated, moisture and volatile matter determinations may be made on both the cake and the dried sludge.

Sampling and Control

The location of sampling points and the number of samples to be collected at each point during a day, will depend on the size of the plant, the degree of treatment required, the receiving body of water, etc. In small plants, grab samples may be permitted, in medium sized plants samples representing several hours out of the day, should be collected and composited. In large plants samples should be collected every hour and composited for the 24 hour period. Where composite samples are used a refrigerator is necessary in the laboratory.

Laboratory equipment in any sized plant should be housed in a separate room (or rooms) well equipped with benches, sinks, drawers, cabinets and other normal laboratory fixtures. For many tests there are now special instruments for making the necessary determinations; such equipment is recommended for the larger plants.

FOR WATER WORKS

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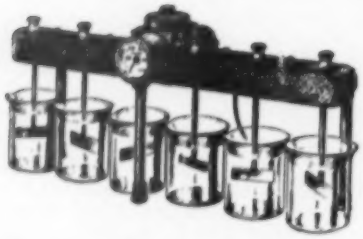
Multiple Stirrer



When several samples are mixed simultaneously under identical conditions the optimum concentration of flocculent may be quickly selected and translated to plant quantities. . . . The mixer takes 1,000 ml. beakers. Speeds from 10 to 100 r.p.m. are standard.

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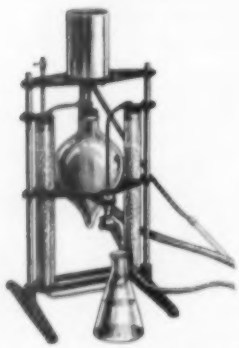

For checking the equilibrium of a finished water, and supplying an index useful in controlling anti-corrosion treatment.

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Effluent Sampler

The effluent sampler is the answer to the problem of taking samples periodically from effluent streams, rivers, etc., for compositing and analysis. Mechanical sampling in this manner is more dependable, because the time cycle is more precise, and the volume of each sample is accurately controlled. The only time required of personnel is that involved in changing receivers.

This Effluent Sampler is compact, portable, simple to operate, with a self-priming pump that lifts liquid to a height of six feet, and an easily-regulated by-pass feeder. Practically no maintenance is required.

Full operating instructions are furnished with each instrument. Additional electrical outlets are provided, along with ample storage space for cord or extra tools.

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Improved Water Filtrability Test

by D. H. MATHESON

Supt., Water Filtration Plant, Hamilton, Ont., Canada

ONE serious deficiency in the laboratory control of water purification processes is the lack of a suitable method of measuring the varying resistance of water to filtration. Many years ago, Sir Alexander Houston devised a method to obtain semi-quantitative values for the resistance to filtration of waters having a varying algal content. His method suffered because of the lack of reproducibility of results, due to the cloth filter medium which he employed. It was not until 1946 that Boucher[1] placed the determination of filtrability on a sound basis, both mathematically and experimentally, and so provided an additional valuable aid in filtration plant operation.

This article deals with the results of a two-year study of the filtrability of raw and treated water at the Hamilton Filtration Plant treating water from Lake Ontario. Laboratory determinations of the filtrability of individual samples have been correlated with the plankton content, the actual filter runs, and certain other variables, and have been applied to the laboratory evaluation of plankton-removal treatments. The laboratory determinations have been supplemented by the use of a recording filtrability meter, and together they have yielded valuable operational information not otherwise available.

Filtrability Index Apparatus

The laboratory determination of the filtrability index uses an apparatus of the type devised by Boucher, as shown schematically in Fig. 1. A stream of filtered water, *A*, passes through a constant head device, *B*, and through a stopcock, *C*, to a cotton plug filter, *D*. At the top of the tube containing this filter is a trap to remove entrained air bubbles which are vented as required through the cock *E*. The stream of water then flows downward through the filter membrane, *F*, clamped between two separable brass adapters, *G*, and thence through a flow-regulating needle valve, *I*, to a flowmeter, *J*. A differential manometer, *M*, connected to the adapters above and below the filter membrane, indicates directly the loss of head across the filter occasioned by the flow rate indicated by *J*. Provision for introducing the measured volume of sample is made by the funnel and cock, *S*.

The unique feature of this apparatus is the filter membrane, a one-half inch disc of "microscreen" mounted in a brass holder, and supplied through the courtesy of Dr. Boucher. The microscreen is a remarkable fabric woven of stainless steel wires, which presents apertures of a maximum diameter of 35 microns. It is structurally strong, identical when one disc is compared with another, very stable in its filtering properties as used in this apparatus, and readily and quickly cleaned after use. The fabric is produced on a commercial scale for use in apparatus designed for plankton removal in water treatment[2].

Operation of the Apparatus

The filtrability determination is made by establishing a constant flow of water through the apparatus, as indicated by *J*. The loss of head occasioned by this flow through the clean filter is recorded as H_0, and amounts to 8-10 cm at a flow rate of 200 ml per minute. The sample is then introduced by operating cock *S* and cock *C* simultaneously. When this is completed, the flow of clean water is re-established by reversing the two cocks at the same time. The flow is then readjusted to the original value by means of *I*; and the loss of head, H_1, through the filter and the deposited mat of particles from the sample, is read from the manometer. The disc is then removed and cleaned. By using a forceful jet of water, no difficulty is experienced in restoring the disc to its original resistance. The whole determination can be performed in a very few minutes and is highly reproducible.

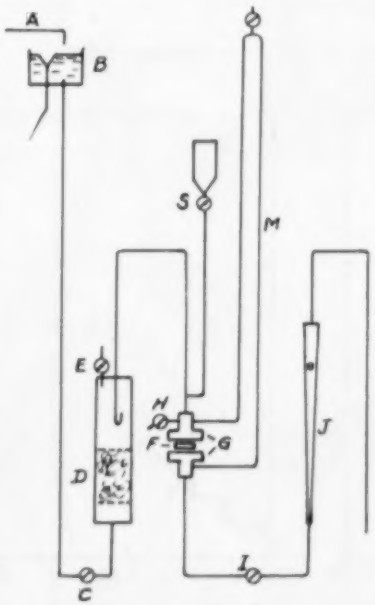

Fig. 1—FILTRABILITY INDEX apparatus, the laboratory setup.

The filtrability index, *I*, is defined by Boucher as follows:

$$I = 0.385/V \times ln\ H_1/H_0$$

where *I* is the filtrability index,
V is the volume of sample in units of 100 ml.,
0.385 is a constant applicable to the microscreen filter, and
H_0 and H_1 are the initial and final loss of head values in any consistent units.

The filtrability index determined in this way is independent of the viscosity of water if the clean water flow is at a constant temperature. Within certain limits the index is also independent of the volume of sample filtered. The volume, however, should be chosen so that the ratio H_1/H_0 is at least 2.0 (in order to obtain accurate manometer readings), and less than 4.0 (to avoid forcing part of the filter mat through the screen by excessive pressure).

It is convenient for rapid work to prepare a table showing, for a unit volume of 100 ml, the values of *I* corresponding to the ratio H_1/H_0 within this range. For samples of other size the value of *I* is readily obtained from the table by multiplying by the appropriate factor. The filtrability index of perfectly clean water is 0.0, and increases as the amount of particulate matter increases.

Seasonal Variations

Since the filtrability index is a measurement of the total amount of particulate matter in water, it may be expected to vary seasonally as the plankton content varies. Fig. 2 shows a plot of the index of the Hamilton Filtration Plant raw water for June and July, 1954, during which period the turbidity remained within the narrow range of 2-5 ppm. The summer increase in the index, from 0.2 to 0.4 in the winter, did not appear in this year until the beginning of June, and reached a maximum value of 2.8 during the middle of July. This highly significant increase in resistance of the water to filtration closely paralleled the plankton counts made on the same

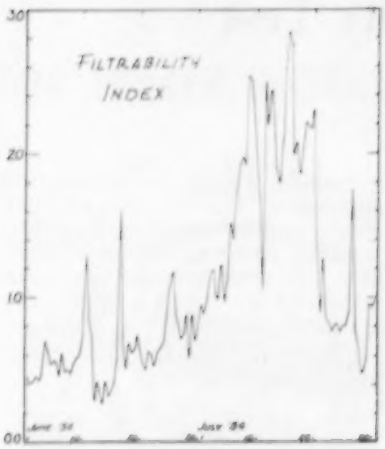

Fig. 2—FILTRABILITY index plot
Raw water, Hamilton, Ont., plant
(Index parallels plankton counts)

samples used for the index determination.

The rapid fluctuations in the index are accounted for by the oscillations of a well-defined thermocline which is frequently established in the lake at a depth approximating that of the intake mouth. Caused by variable winds, these oscillations result in the intake receiving at different times water from above, at, or below the thermocline. Since the plankton concentration is greatest just above the thermocline, rapid changes in plankton counts and in filtrability index are exhibited, and are associated with corresponding changes in water temperature.

Index Correlation

An exact correlation between the plankton count and the filtrability index would be highly desirable, but on consideration of the nature of the variables involved, it is scarcely to be expected.

Fig. 3 shows three sets of data obtained at different times when careful plankton counts and filtrability index determinations were made on the same samples. The difference in the slope of the trend lines indicates that factors other than the areal standard units of plankton affect the index. These factors could be determined by a difference in the plankton species involved; by general growth characteristics such as the length of filaments and the existence of a gelatinous coating; and by the presence of amorphous particulate matter not normally included in plankton counts, occurring in quantities too low to cause appreciable turbidity.

A very fair correlation is obtained when the filtrability index is plotted against the length of run of the plant filters, as shown in Fig. 4 where data of July 1954 are plotted. The curve is calculated on the assumption that the runs of plant filters vary in length as the reciprocal of the index. The scatter observed here is attributable not only to the above variables but also to the effect of varying temperature on the runs of plant filters. We must recognize the fact that the index is based on individual spot samples collected from a variable raw water, while the filter run figures represent an average of the raw water variations over a period of hours.

Automatic Metering

Since the determination of the filtrability index is of definite value in the operation of a filtration plant, it appeared advantageous to have an instrument capable of performing the determination automatically at frequent intervals, and of recording the results. Boucher patented such an instrument in 1951[3]. A somewhat similar device embodying an available electric meter was constructed at Hamilton in 1952, and has been operated almost continuously since then. The record from this instrument provides a much more detailed record of the raw water variability than can be realized from taking a few spot samples each day. A sample of the data plotted from meter records is shown in Fig. 5. The meter record is slightly affected by changes in water temperature, but by far the greater part of the variation shown actually is due to the changing filtrability of the water.

Meter Operation

A schematic diagram of the recording meter is shown in Fig. 6. We used an old-style G.E. recording watt-hour meter, incorporating a kelvin balance. The mechanical portion of the balance, *A*, with the coils removed, was converted to a recording manometer by utilizing the changing weight of a plastic rod, *B*, suspended from one end of

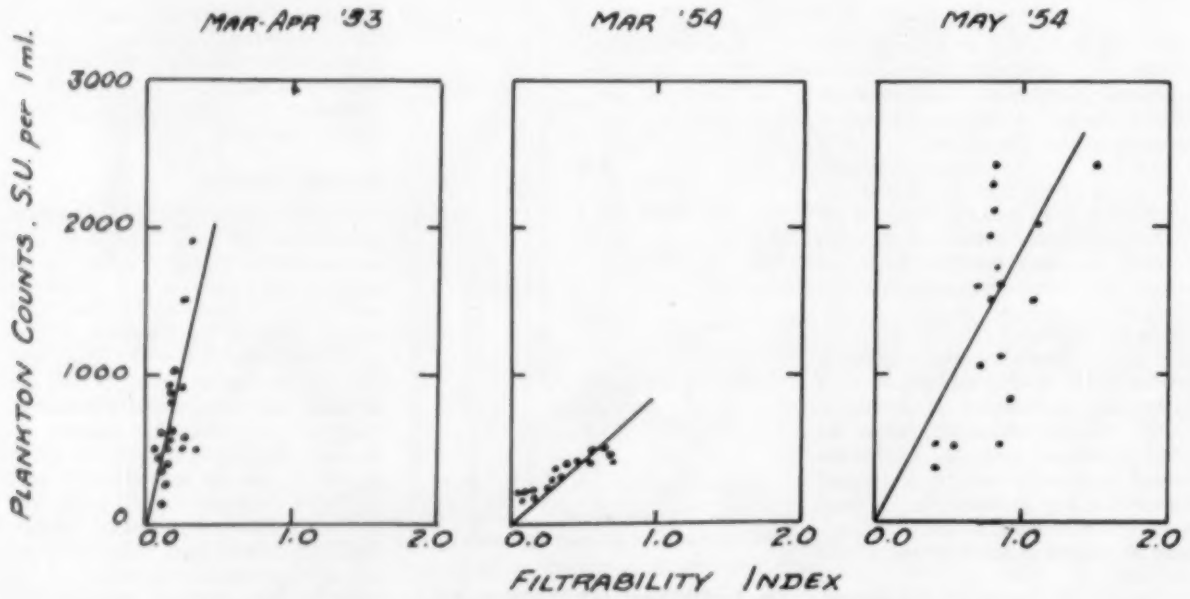

Fig. 3—FILTRABILITY index compared with plankton counts made on the same samples

the balance arm and partially immersed in water in the manometer, *C*.

In this unit, it was necessary to use as the filter medium a shallow bed of very fine sand in place of the micro-screen disc. The sand was used since it would be difficult to wash the micro-disc adequately without the use of a jet of water.

Meter Calibration

The four valves *E*, *F*, *G* and *H* are operated by a solenoid and function in pairs, as in normal filter operation. The filter effluent passes through valve *H* and to an orifice, *I*, which serves to maintain a substantially constant flow since the maximum loss of head (amounting to about 10 cm) is small compared with the total head applied to the orifice.

At the start of a run the recorder pen leaves the left-hand side of the chart and draws a curved line, plotting the loss of head of the filter against time and therefore against volume filtered. When the pen reaches the right-hand side of the chart it starts a cycling device, which washes the filter by actuating the solenoid controlling the four valves, and places the filter back in operation again. Immediately thereafter, the solenoid energizes a heavy buzzer clamped to the filter tube; the buzzer vibration, together with the downward flow of water, compacts the sand bed to a reproducible density.

The meter is calibrated by determining the loss of head corresponding to each of two graduations at either edge of the chart. From these values, H_1/H_0 is obtained. The number of minutes required by the pen to travel between these two lines is proportional to the volume of water filtered. If, then, *I* is determined in the laboratory on the water sample delivered to the meter, a value can be calculated for the constant in the filtrability equation. Since H_1/H_0 remains constant, I_m, the index measured by the meter, varies inversely with the time interval indicated by the chart.

The instrument is operated as a secondary device only, being kept in constant calibration by frequent checks with the laboratory determination. The instrument readings therefore serve to complete the record provided by the spot samples determined by the manual method.

Additional Applications

In addition to its value in interpreting plant performance, the filtrability index is an attractive means for studying on a laboratory scale the effects of specific water treatments, especially those designed for plankton removal.

Storage of water in the laboratory results in a reduction in *I* amounting to as much as 33 per cent in one week, presumably caused by the disintegration of organisms which have died under prevailing unfavorable conditions.

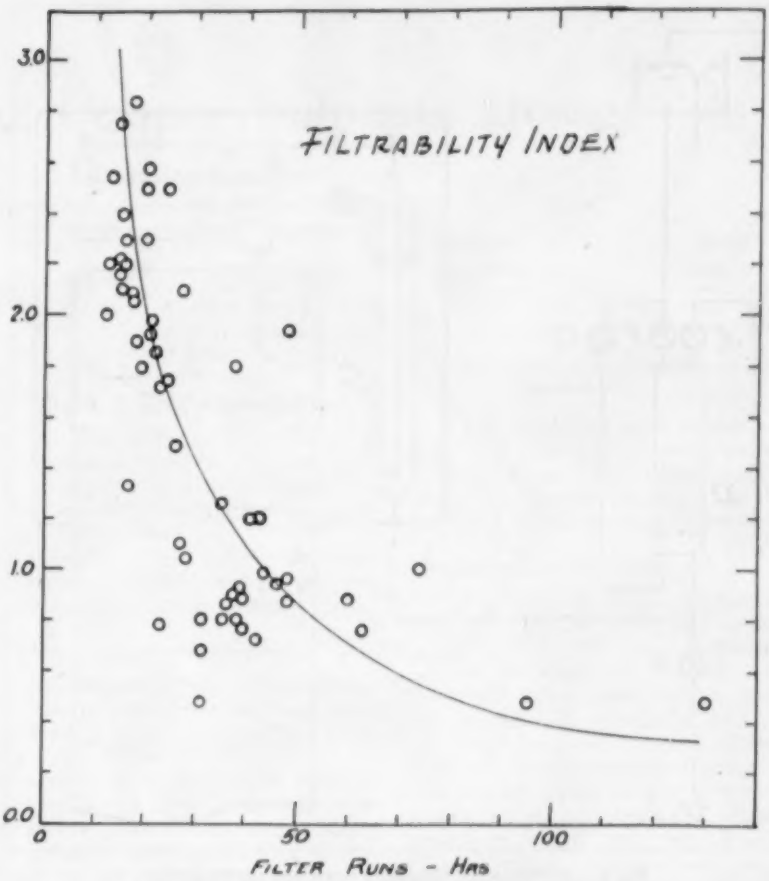

Fig. 4—CORRELATION curve of filtrability and filter runs

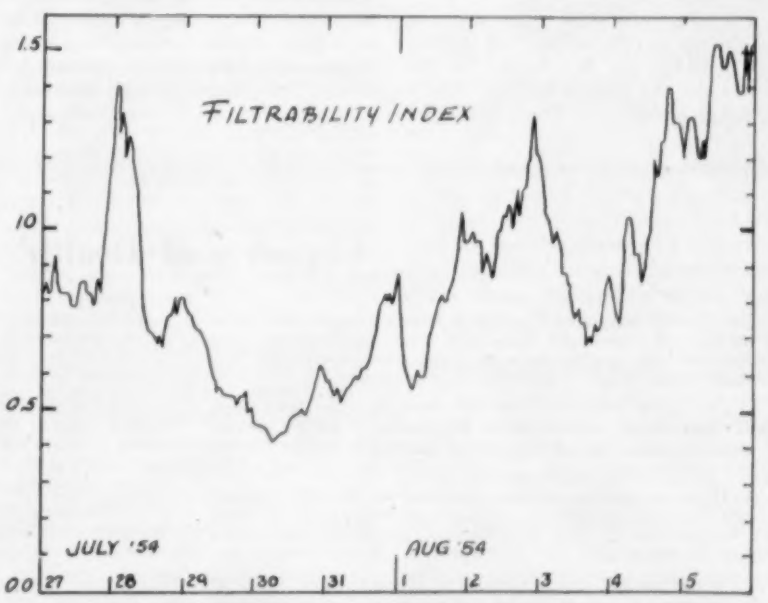

Fig. 5—FILTRABILITY index determined by automatic recorder

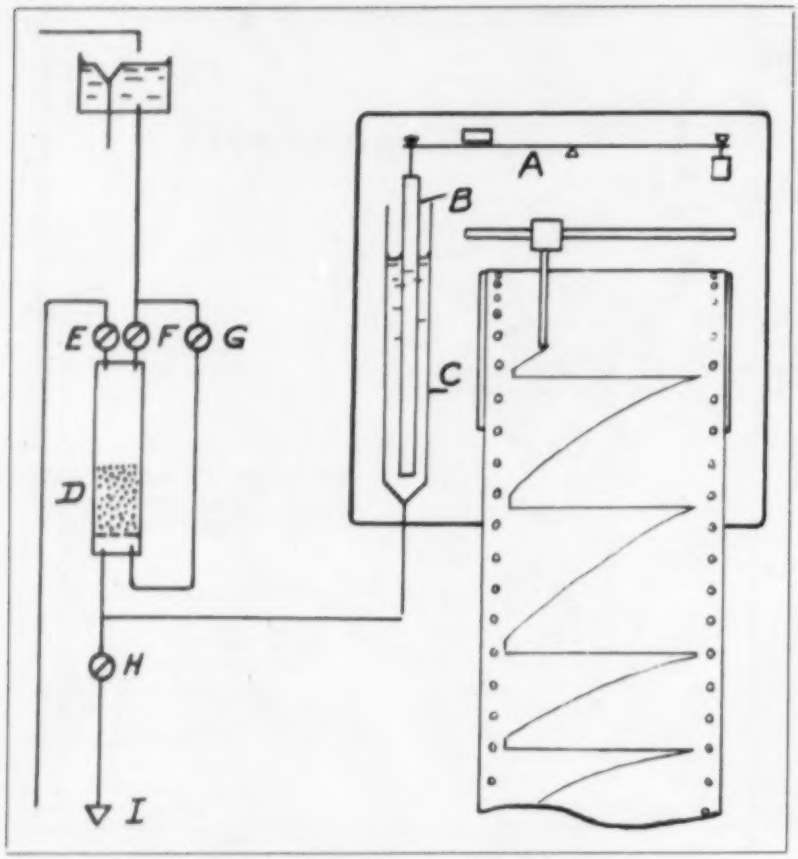

Fig. 6—AUTOMATIC filtrability meter and control device

The effect of sedimentation is readily demonstrated, but it has been noted that settling in laboratory vessels takes place much more rapidly than in the plant basins.

The effectiveness of varied doses of coagulants in coagulating and settling our plankton can be assessed by this procedure, but cannot be done readily by other techniques. The initial *I* increases due to the formation of floc, and then decreases significantly as the plankton organisms are entrained and removed by sedimentation.

The effect of increasing doses of chlorine on algae can be followed by employing gentle mechanical stirring to prevent sedimentation. Boucher indicated that *I* increases with increasing chlorine doses up to the break-point and then decreases, apparently due to the coagulation of colloidal matter and to its subsequent destruction by the free chlorine. With a predominantly diatomaceous plankton, however, there appears to be only a slow continuous reduction in *I* with increasing chlorine doses. The chlorine-treated organisms settle more rapidly than do those in the untreated control samples. Treatment of similarly stirred samples with increasing doses of copper resulted in a definite and permanent increase in *I*, presumably due to the coagulation of organic matter. Subsequent settling is not appreciably better than in the control samples.

Conclusion

Continuous yearly records have been obtained, by manual and automatic means, of the filtrability index of raw and applied water. These records provide valuable information in assigning causes for variations observed in the performance of plant filters.

The filtrability index determination is made by the laboratory method more quickly than plankton counting; it appears to correlate better with plant performance, and it is applicable to the laboratory evaluation of treatments for plankton removal.

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1. Boucher, P. L. "New Measure of Filtrability of Fluids with Applications to Water Engineering." *J. Inst. Civil Eng.*, 27:415-46 (1946).
2. Boucher, P. L. "Microstaining." *J. Inst. Water Eng.*, 5:561-95 (1951). Hazen, R. "Application of Microstaining to Water Treatment in Great Britain." *J. A. W. W. A.*, 45:723-37 (1953).
3. Boucher, P. L., and Rowntree, N. A. F. "Means for Measuring and Recording the Filtrability of Fluids." U. S. Patent 2,572,436.

R&D

Copper and Health*

The effect of copper on health is a subject of such importance to all uses of copper and brass and copper sulphate for algae control, that the conclusions in an article read before The New England Water Works Association are given below:

1. The copper content of domestic drinking water after passing through copper or brass pipe or tubing, even if a slight amount of copper is taken into solution, is not harmful to health. It may indeed be beneficial.

2. All water supplies intended for domestic use after passing though a proper installation of copper or brass pipe or tubing will contain but a small pecentage of the permissible copper content, if any at all.

3. The permissible copper content of domestic water based on a consumption of one gallon of water a day should apparently not be greater than 20 p.p.m.

4. It is unlikely that health will be injured by copper because, where the copper content is above 5 p.p.m., the taste of the water will generally be so disagreeable that it will be virtually impossible to drink it.

5. No anxiety need be felt about a proper installation of copper or brass pipe or tubing, because it has been shown that with acid water having a pH value of about 6.5, the copper content is generally only about 0.5 p.p.m., even after standing in the pipe lines for an appreciable length of time.

6. The treatment of reservoirs with copper sulphate to rid them of undesirable microscopic growths has no injurious effect on health.

*Journal N. E. W. W. A., 44: 4, December, 1930.

Determining Copper Sulphate Dosage

By WILLIAM D. MONIE

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EVERY engineering problem, regardless of its complexities, is solved by a common sense application of fundamentals. The problem of algae control is no exception and must be solved by the common sense application of fundamentals pertaining to this problem. It is with these fundamentals which we call the A-B-C of algae control that this paper is concerned.

Canoe Brook Reservoir

The supply at the Canoe Brook station of the Commonwealth Water Co. is derived from a combination of artesian well water and a filtered surface supply. The surface water is pumped from a brook during wet seasons and stored in a reservoir approximately 204 acres in area, having an average depth when full of 11 ft., and a maximum capacity of 735 mg. In an average summer this reservoir constitutes a constantly decreasing but fluctuating volume of water, entirely exposed to light, with water temperatures reaching 80 degrees F.

The reservoir of the Commonwealth Water Co. presents three features which make the control of algae especially difficult. With a maximum depth of only 11 ft. when full, it cannot stratify during the growing season, so the nutrients available for algae development are used over and over again, giving maximum crops. Second, light at all times reaches the bottom where dormant stages of algae lying on the mud are quickly stimulated to activity whenever temperature and other factors are favorable. Finally, the reservoir is subject to marked fluctuations in its level. In consequence, the small bays and inlets, which are often the chief breeding grounds for objectionable algae, are frequently drained of their contents. Thus the entire reservoir is seeded again and again.

Algae control in this reservoir was indeed a problem. Records prior to 1939 show that it was not an uncommon occurrence to experience difficulty from luxuriant growths of algae, especially Anabaena and Aphanizomenon. In 1939, despite frequent treatments with copper sulfate from February through October, taste and odor trouble occurred in October because of abundant growths of Anabaena and Aphanizomenon.

A detailed study was then made of the A-B-C's of algae control with copper sulfate, with especial consideration of our problem.

The A, B, C, of Algae Control

A—The ability to determine when it is necessary to treat a supply.

B—The ability to determine the correct amount of copper sulfate to apply when treating.

C—The ability to apply the treatment so that uniform distribution of the copper sulfate is obtained.

When to Treat

In determining when it is necessary to treat a supply, the most important governing point is a recognition of the fact that one must realize copper application is a preventive measure rather than a cure. Therefore, never wait for consumer complaints before treating; treat in ample time to *prevent* the complaints.

The best method of determining when it is necessary to treat a supply is by microscopic examination. When an organism is growing to such a point that it may cause trouble, daily microscopic examination and count should be made of samples taken directly from the reservoir. From the count and speed or rate of growth, it can be determined when the supply should be treated.

There are two points in the above paragraph which should be stressed: 1—Samples should be collected directly from the reservoir for microscopic examination. If samples are collected from a main, or after passage from a pump, delicate organisms are broken up and some become unrecognizable. 2—In the growing season daily microscopic examinations must be made. It is surprising how rapidly organisms increase in number when growing conditions are ideal. It is not uncommon to have an organism more than triple its numbers within one to two days.

From experience at the Canoe Brook reservoir certain upper limits of safety, beyond which treatment was necessary, were determined for each organism. These are—

Organism	Count*
Asterionella	1,000-1,200
Mallomonas	800-1,000
Anabaena	600- 800
Aphanizomenon	300- 600

*Total number of organisms in ten fields at a magnification of 100x.

It was decided to apply copper sulfate only when an organism reached these limits, as it had proven uneconomical to attempt control when the organism is just starting to increase.

Keep an Eye on the Thermometer

The growth of different types of organisms can be anticipated by the temperature of the water, especially surface temperatures. According to Nelson[2], "approximately twenty years ago Dr. Setchell, botanist of the University of California, pointed out that there are definite ranges of temperature within which various flowering plants begin to grow and higher ranges at which they will flower. These critical temperatures were found to lie close to 5°, 10°, 15°, 20° and 25° C. (41°, 50°, 59°, 68° and 77° F.) His studies showed that as the temperature passed the critical point certain species were suddenly stimulated to activity. Hydrobiologists working with algae and protozoa are finding similar critical temperatures. Owing to the more gradual temperature changes which occur in the water, these ranges are more easily recognized and delimited than is the case with land plants."

It has been our experience that different species of algae have started to grow at these temperatures. Therefore, as the temperature of the water reaches these critical temperatures get out your microscope and keep a close watch on the algae growth.

How Much Copper to Apply

It was with this factor—how much copper sulfate to use in treating—that we experienced the most difficulty. Many times what appeared to be an effective treatment three days after the application of the salt found an aftergrowth of the same organism within a week of treating that reached greater numbers than were present before the sulfate was applied.

Many Factors Govern Dosages

In regard to the question of the amount of copper sulfate to use in treating a supply, Hale[1] states: "Experience differs with waters of different composition, with temperature and with the amount of organism present as to the right dosage to apply for each organism. It is a waste of chemical to apply an insufficient amount. If a smaller dosage fails, the entire larger dosage must be applied at one time."

Therefore, it is *a waste of chemical to apply an insufficient amount,* just as it is a waste to apply an excess amount.

We used the table based on data by Moore and Kellerman, Whipple and others[1] as a starting point, and attempted to apply it to conditions existing at our plant. However, one of the organisms with which we experienced considerable difficulty was Aphanizomenon. The table gave a range of 1.0-4.2 pounds per mg. for the control of this organism. Furthermore, past experience showed that treatments of 1, 2, 3 and 4 pounds per mg. had all been effective for the control of Aphanizomenon at one time or another. We realized that if we treated for Aphanizomenon with 1 pound of copper sulfate per mg. when 4.2 pounds per mg. might be needed, the 1 pound per mg. treatment would be wasted, since the 4.2 pounds per mg. must be applied at one time to be effective. Likewise, if the 4.2 pounds per mg. was used and 1 pound per mg. would have done the work, then 3.2 pounds per mg. would be wasted.

With so many factors influencing the amount of copper sulfate to use in treating a supply, algae control would certainly be much more scientific if we had a test that would allow us to say definitely how much copper sulfate it was necessary to use to satisfy all conditions. In September of 1940 the author devised a simple, practical laboratory test to determine the amount of copper sulfate necessary to use in treating a supply of water regardless of its temperature and composition and, within certain limitations, regardless of the type and amount of organism present.

The "D. M." Test

It was found that the addition of certain amounts of copper sulfate to water containing algae resulted in an increase in the alkalinity. The amount of copper sulfate needed to bring about this increase in alkalinity was the correct amount to use in treating. After much experimentation the following test was developed.

The equipment and chemicals necessary for the test are as follows:

a. Six 50 ml. nessler tubes.
b. A copper sulfate solution of a strength that 2 ml. added to a liter of water equals a copper sulfate treatment of 1 pound per mg.
c. Phenolphthalein indicator.
d. 0.01136 N Na OH

To make the copper sulfate solution mentioned in b, dissolve 0.6 gram of the copper sulfate you use in 1 liter of distilled water. Dilute 100 ml. of this solution to 1 liter with distilled water. Two ml. of this final solution per liter of sample equals one pound of copper sulfate per mg., or 0.1 ml. per 50 ml. of sample equals one pound of copper sulfate per mg.

Test Procedure

In each of six 50 ml. nessler tubes A, B, C, D, E and F, 50 ml. samples of the water to be treated are placed. To tube A, add 0.1 ml. of the copper sulphate solution (b) to equal a treatment of 1 pound per mg.; to tube B, 0.2 ml. of solution (b) is added to equal a treatment of 2 pounds per mg.; to tube C, 0.3 ml. of solution (b) is added to equal a treatment of 3 pounds per mg.; to tube D, 0.4 ml. of solution (b) is added to equal a treatment of 4 pounds per mg.; to tube E, 0.5 ml. of solution (b) is added to equal a treatment of 5 pounds per mg. To tube F, no copper sulfate is added. These samples are then mixed by corking and inverting approximately thirty times simultaneously.

To the nessler tube F (the blank sample) phenolphthalein indicator is added. If there is a negative amount of free carbon dioxide present, enough indicator is added until there is a faint but distinct pink color. Then the same amount of phenolphthalein is added to each of the other samples. The samples are compared and the tube with the deepest color is the tube containing the sample to which has been added the correct amount of copper sulfate to use in treating.

Influence of Carbon Dioxide

If there is free carbon dioxide present(and there usually is), three drops of phenolphthalein is added to each of the six samples in the nessler tubes after they have been mixed with the various amounts of solution (b) as described above. Then 0.01136N sodium hydroxide is added to the nessler tube F (the blank sample) until there is a faint but distinct pink color. The same amount of the sodium hydroxide is then added to the other five samples and the tubes are compared for color. The deepest color will be found to be in the tube containing the sample to which the most effective and economical amount of copper sulfate to use in treating has been added.

This test is practically the same as a free carbon dioxide titration. However, in the algae test it is simpler to have both the phenolphthalein and the sodium hydroxide in dropper bottles, as the equal amounts can be easily added to the sample tubes by counting the drops. 0.01136N sodium hydroxide is used simply because finer control can be maintained on the color. In waters with considerable carbon dioxide, 0.02272N can be used just as effectively.

It is important to note that the tube with the deepest color is always darker than the blank sample. Therefore, at the correct dosage of copper sulfate the water is more alkaline than it was prior to the addition of the salt. This result is clearly shown in the test irrespective of the fact that phenolphthalein is not a sensitive indicator. The puzzling factor of the entire test is the fact that at a certain concentration of copper sulfate dosage the alkalinity is increased, and then with an excess of copper sulfate the alkalinity decreases to approximately the same point as it was in the blank sample. Therefore the color in the tubes rises gradually with the dosage increase and after reaching a maximum the overdosage causes a lessening color development.

When the "D. M." test was first developed the author used a mixing machine with liter samples instead of the nessler tubes. However, the reaction in the test is so fast that the results can be obtained quicker with equal accuracy using the nessler tubes.

If more than one type of organism is present in sufficient numbers it is possible to get two or more treating points by the "D. M." test. For example, Anabaena and Aphanizomenon were present at the same time in the water at Canoe Brook reservoir. The "D. M." test showed two distinct treating points, two pounds per mg. and four pounds per mg. To use two pounds per mg. would have been a mistake as only the Anabaena would have been destroyed, which would leave conditions perfect for the rapid-increase of the Aphanizomenon.

Proper Method of Copper Application

Proper distribution of the copper salt through the reservoir water is important to successful algae control. Knowledge of the first two steps for algae control—when to treat, and how much salt to use in treating—would be of no value without proper applica-

tion of the chemical. For example, if a four-pound per mg. treatment of copper sulfate is necessary, then the salt must be applied so that the water in all parts of the reservoir has received approximately a four-pound per mg. treatment. The deeper parts of the reservoir must receive in proportion more salt than the shallow parts. If this is not done, some portions of the water will be undertreated and the algae not killed in these parts will remain to re-seed the reservoir.

Here, again, a detailed study of conditions of each reservoir must be made and the method of application decided upon after careful deliberation. In the majority of lakes the best method of application is by dissolving the copper sulfate from burlap bags or perforated boxes attached to a boat. However, in some lakes and for certain types of algae some other method of application such as spraying either a solution of copper sulfate or broadcasting the pulverized dry salt may be more practical.

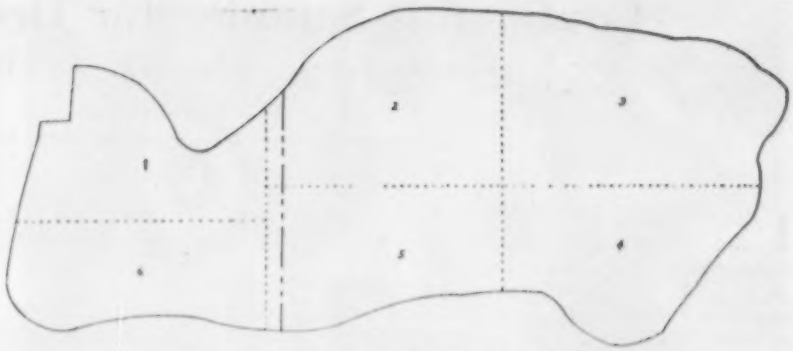
Knowledge of Reservoir Topography Important

In order to obtain proper uniform distribution of the chemical a knowledge of the reservoir bottom topography is an important consideration. If you do not have a contour map of the reservoir bottom, make one. The points for preparing such a map are easily obtained by soundings from a boat or from the ice in northern regions.

When the reservoir bottom topography is known it is a simple matter to section the reservoir into areas of approximately uniform depth. With this knowledge it is possible to apportion the salt in treating so that equitable application can be planned and made. In deep reservoirs usually only the top twenty feet need be considered in treating.

Method of Applying Chemical

At the Canoe Brook reservoir the treating is done by means of a boat propelled by an outboard motor. The chemical is placed in two burlap bags, one on each side of the boat, suspended from frames so that additional salt can be added to the bags to keep the amount of salt exposed to the water uniform. The strength of the treatments is regulated by the level of sulfate carried in the bags.



Diagrammatic Sketch of Canoe Brook Reservoir

The dotted lines show how reservoir is sectioned for purposes of sampling water and applying copper sulfate in correct proportion to water depth and algae concentrations. During algae growing season each section is sampled daily and given microscopic examination—believing that the old adage about an ounce of prevention being worth pounds of cure holds nowhere more pronouncedly than in algae control.

The conventional strip method is used in treating. After experimenting, the strips now used are approximately forty feet wide. This width of strip allows the reservoir to be treated in an eight-hour day with one boat. The same width of strips is adhered to regardless of the amount of salt per treatment, the amount of salt going into solution depending upon the amount exposed to the water.

In a case where a reservoir is so large that strips over 100 feet are necessary, more than one boat should be used in treating.

Results

The following table illustrates the results obtained over a seven-year period from 1939 through 1945 at the Canoe Brook reservoir. In five of these years the copper dosage was determined through the use of the "D.M." test.

Year	Treatments	Lbs. $CuSO_4$
1939	37	33,750
1940	7	11,250
1941	8	14,350
1942	3	6,200
1943	2	3,700
1944	3	5,200
1945	3	5,200

As shown by this table gratifying results were obtained by practical application of the fundamental A-B-C of algae control. From the last treatment in 1940 the "D.M." test was used in determining the amount of copper sulfate to use in treating.

There has not been a treatment where the amount of salt used was determined by the "D.M." test that was *not* successful. Additional success since 1941 is believed to be due to changes made in applying the fundamentals of when to treat and how to apply the salt.

One interesting observation during systematic use of the "D.M." test is that the amount of salt necessary to destroy certain organisms increases as the number of the organisms present increases until a certain point is reached and then the amount of salt required decreases as the organism continues to increase in numbers. This circumstance is unexplained.

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(1) Hale, Frank E., "The Use of Copper Sulphate in Control of Microscopic Organisms." Phelps-Dodge Refining Co., New York. (Revised 1935.)

(2) Monie and Nelson, "Algae Control," *Jour. A.W.W.A.*, April, 1941.

Continuous Sampler for Deep Sewers*

Design Features of a Reliable Automatic Device

by JEROME WILKENFELD

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IN THE course of pollution abatement work at the Hooker Electrochemical Company, Niagara Falls, N. Y., it became apparent that, in addition to the normal sampling of process effluents, continuous sampling of effluent streams on a 24-hr. basis would supply additional valuable information on over-all conditions in the plant. Since the major proportion of the products produced at the plant are organic in nature, it was felt advisable to construct a sampler so that a 24-hr. composite sample could be collected of suitable size for extraction purposes, this sample to be collected directly in a bottle that could be handled in the laboratory without transferring. With this in mind a continuous automatic sampler was designed and installed on the main sewer leaving the plant. This sewer is located approximately 20-ft. below grade and has a relatively steady flow.

The first sampler built attempted to use a positive displacement pump located above ground with a long suction line extending down into the sewer. Pump life was extremely short, however, because even small amounts of suspended solids caused sufficient wear to reduce the pump suction below the required amount. Plastic pump parts failed due to absorption of trace amounts of organic solvents, which caused swelling. In addition, unless a pump received almost immediate attention when it lost its prime, the pump burned out due to running dry at the relatively high speeds required for operation. In all, three types of positive displacement pumps were tried.

Collection of relatively small samples at frequent intervals with a system of timers and valves also caused frequent shutdowns due to plugged valves and timer failures.

With these limitations in mind, it was decided that a pump that would operate with a minimum suction lift and at a low speed would be most suitable. At the same time, most of the pumping equipment must be kept out of the sewer, due to the hazards of sewer atmospheres. It was also felt that the sample collection itself should be carried out without the use of timers or valves and yet sample size and frequency had to be closely controlled.

Sampler Description

Such a sampler has been developed, and has been in operation since 1951 with only minor modification. This sampler is reliable, rugged, and capable of operating for long periods with a minimum of maintenance. Five of the samplers are now in use in the plant; four are considered semi-portable and are moved to branch sewers as desired to assist in determining the quality of effluents in localized areas.

The schematic layout of the sampling equipment is shown in Figure 1, the complete unit in Figure 2. The principle of operation consists of using a deep-well pump, with the cylinder located just above the water level, to pump a continuous stream of approximately 5 g.p.m. of water from the sewer. This stream is piped over a sampling tap, which is allowed to flow continuously to a drain cup. All water not taken as a sample is returned to the sewer through a drain line. Mounted adjacent to the sampling tap is a ⅓-r.p.m., 110-v. motor carrying a 3-cc. glass sample cup pivoted from the top. In the course of the rotation, the cup passes through the falling stream of water and is then tripped by a rod, dumping the sample into a collection bottle. The deep-well pump used has a 6-in. stroke and is modified to use a two-leather differential plunger seal. The cylinder used is a brass-lined artesian well cylinder with 10-in.

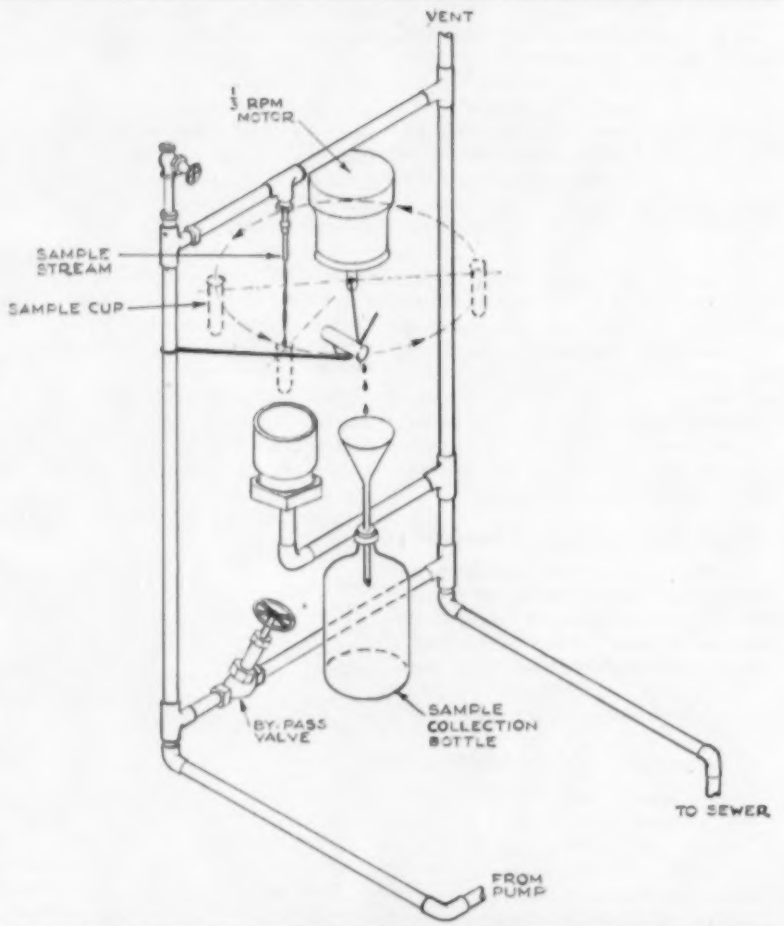

Fig. 1—Construction details of automatic sampling device.

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stroke and 1 3/16-in. inside diameter.

It should be noted that all piping is of 310 stainless steel and that the box containing the pump and sampler is mounted on a pedestal base to allow air circulation between the manhole cover and the equipment. This was done when it was found on previous types of samplers that flush mounting caused excessive corrosion due to moisture condensation from sewer breathing. An additional advantage is the accessibility of the well line coupling allowing disconnecting and removal of the well line without disturbing the pump and housing.

Advantages of Sampler

In effect, a portion of the sewage stream is brought above ground to the sampler. The sampler can be further modified to handle other situations. The sample size is easily adjusted by changing the cup size, while the frequency of sampling is changed by use of a different speed motor. Should the collection of samples by periods be desired, a timer-actuated sampling table can be added.

Unit described has the following advantages:

1. It is a slow-speed machine with no delicate timers or valves which are susceptible to fouling.

2. The construction of the pump and sampling mechanism allows satisfactory sampling of streams containing suspended solids or other miscellaneous materials.

3. The sample is rapidly delivered from the stream with little time lag, should this be advantageous (as in the case where a record or control of pH is desired). This is done on one installation in the plant, where the sampler is used for sampling purposes and for pH recording simultaneously.

4. Maintenance on the equipment is low, with the pumping head requiring only occasional lubrication. The cylinders last upwards of three months, depending on the location and the type of sewage handled. On occasion, when feed lines have been blocked, the pumps have run dry for periods of more than 18 hr. without any apparent injury. Several sampling motors have been in service for over a year without any repairs being required.

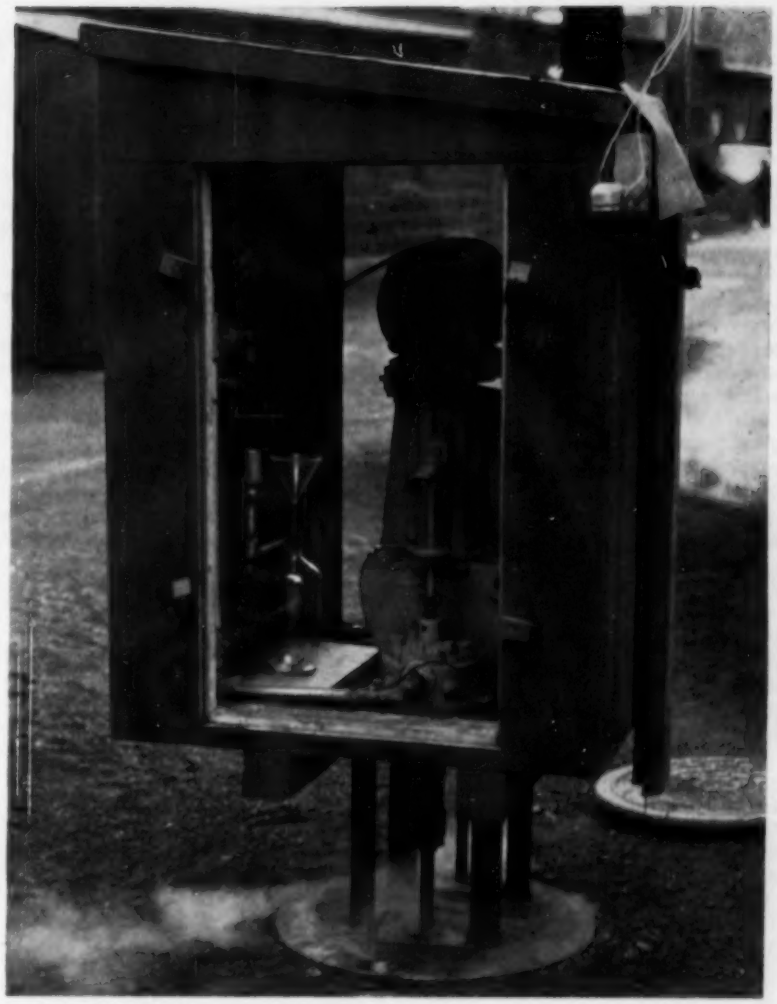


Fig. 2—Sampler in operation; note housing for protection.

In general, it has been found that this type of sampling equipment is not only adaptable to many types of sampling problems, but also is ideally suited for sampling from deep sewers or other relatively inaccessible locations. The ability to handle streams containing solids without plugging, together with the mechanical reliability, make this a suitable sampler where operation with a minimum of attention is desirable.

MAINTENANCE

MAINTENANCE comprises those operations which serve to keep equipment and processes functioning properly without interruption. Repairs, on the other hand, are those steps undertaken to restore broken or worn out equipment to operation. These two terms have frequently been used somewhat interchangeably. Some writers, therefore, have used the term "preventive maintenance" to avoid any possible confusion with simple repair operations.

In both water and sewage works, good plant control includes a program of preventive maintenance, for it has been said that "preventive maintenance is insurance against costly breakdowns."

Essentials of Good Maintenance

There are four basic elements in preventive maintenance. These are a thorough knowledge of the equipment or process, proper tools, adequate replacement or repair parts, and a planned program.

Knowledge of equipment can be gained from manuals of instruction furnished by the manufacturer with the equipment. Knowledge of processes and process operations can be gained from standard text books and magazines such as the Reference and Data Edition of WATER & SEWAGE WORKS.

Special tools may be required for particular apparatus, instruments, machines and equipment or particular maintenance operations. Regardless of the type of tool or its use, they should be adequate and properly sized for the function they are to perform. Furthermore, tools should be located in a specific place and returned there after each use. A good motto is: "A place for everything, and everything in its place" whether it be a delicate instrument, a Stillson wrench, a carpenter's level, or machinist's file.

Replacement or repair parts, commonly called spare parts should be stocked in numbers according to the number of machines to be serviced and the operating life of the part. Like tools, spare parts should be carefully and correctly labelled and kept in a specific location.

Planning a maintenance program is the job of the superintendent or manager of a water or sewage works.

Planned Maintenance Program

A preventive maintenance program should be set up for every piece of equipment, every structure, and every unit process in a water or sewage works system. This program should be aimed at accomplishing the overall desired objective of preventing costly breakdowns or loss of effectiveness and efficiency. Such a program will involve several factors.

1. Regular periodic lubrication, inspections, cleaning, and replacement of worn parts.
2. Systematic distribution of maintenance operations so that such operations on different equipment will not fall due at the same time.
3. Systematic scheduling of maintenance so that it will be done on a definite periodic basis. The use of a card record system avoids dependence on memory.—"A piece of paper never forgets."
4. A method for adjusting the inspection period to fit conditions as experience indicates.
5. Record cards to show date of maintenance, type of maintenance performed, condition of equipment, repair parts used, time spent on maintenance operation, and costs.

General Maintenance Operations

There are certain fundamental operations that can be applied as a part of any preventive maintenance program.

Standby equipment should be operated at regular intervals as should any equipment used infrequently. Inspection of all equipment should be the first step in every maintenance program. Cleaning operations are essential to maintaining anything in good operating condition. Lubrication at regular times with the proper lubricant is a must for equipment whose operation involves friction.

Equipment and facilities should be protected against damage from careless operation, and from careless or destructive passers by. Whenever necessary worn parts should be replaced and complete disassembly, cleaning and repairs may be desirable for some equipment at regular, if protracted, intervals. Corrosion may be prevented by applying protective coatings.

Specific Maintenance Problems

Among the many maintenance problems which arise there are some which stand out, either because they are unique or because their true maintenance character is not always recognized.

One of the most important maintenance operations is that of maintaining the carrying capacity of water mains and sewer lines. Corrosion and incrustation or slime formation in water lines often causes a serious loss in carrying capacity and pressure loss. Cleaning, or cleaning and lining, is the maintenance operation to be performed. Sewer lines may tend to become clogged with debris, stranded particles, settled grit and slime growths. Cleaning at regular intervals is required, but there is no protective lining that will help. In both water and sewer lines where slime growths tend to clog or reduce carrying capacity, the application of chlorine on a regular schedule is a preventive maintenance operation.

Cleaning of wells or performing operations that will assure continued full supply is termed maintenance. Filter washing is a maintenance operation, just as is the replacement of lost sand. Cleaning sludge beds in a sewage plant and replacement of sand are likewise maintenance operations. So too, is the washing of vacuum filter cloths (with or without acid) to increase the life of the cloth.

Maintenance Equipment and Services

To aid the superintendent or operator there are many pieces of special equipment which can be obtained from manufacturers. There are also maintenance services which can be obtained. Outstanding examples of special equipment include that for cleaning sewers.

Special maintenance services can be obtained to clean and reline water mains. Manufacturers of lubricants will gladly study any plant and develop both a list of the minmum lubricants required and a lubrication schedule. Paint and protective coating manufacturers offer free consultation and recommendations on preventing corrosion problems.

Many manufacturers of equipment offer a maintenance service program, whereby for a minimum fee and prorated expenses, a factory service man will make regular scheduled trips to the plant. Services rendered include disassembly, cleaning, lubrication, replacement of worn parts, indication of parts showing signs of wear, reassembly and adjustment. This service is particularly useful on complicated mechanisms, instruments, etc. in plants which cannot afford to have specialists on their maintenance staff.

Preventive Maintenance Practices*

by F. A. SANDERS
Lt.-Col., U.S.A.F. Institute of Technology, Air University Command
Wright-Patterson Air Force Base, Ohio

MAINTENANCE employed at sewage and industrial waste treatment plants may be (a) preventive maintenance, (b) breakdown maintenance, or (c) a combination of the two types. The emphasis in this paper is on preventive maintenance.

Preventive maintenance can be defined in a number of ways, but essentially it is a scheduled maintenance program for keeping the equipment and structures in a good state of repair. It corrects faults in the early stages, thereby preventing major breakdowns or interruptions.

Any plant that conducts a "breakdown maintenance" system only, that is, one that maintains only that equipment which breaks down, is using the wrong system and can save money and reduce headaches, accidents, and interruptions by changing over to preventive maintenance.

Preventive maintenance can be used in all sizes of plant, from the smallest to the largest. It will work whether maintenance is being performed by the operators or by separate maintenance personnel.

For many years large industries have practiced preventive maintenance. The program of preventive maintenance described in this paper is essentially that used in the United States Army and Air Force.

Essential Requirements

Certain requirements are essential to any successful preventive maintenance program. They are as follows:

1. Training of all operators or maintenance personnel in proper operating procedures and preventive maintenance practices.
2. Systematic and periodic inspection and servicing by skilled personnel.
3. Assignment of specific maintenance responsibilities to operating personnel.
4. Supervision of the program.

If any one of these requirements is not contained in the program, the program stands less chance of being successful.

Training

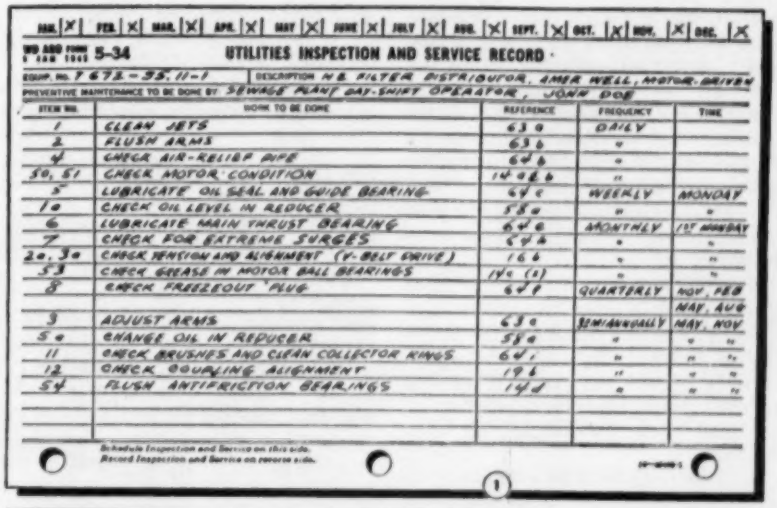
Training not only includes instruction in technical maintenance procedures but also must explain to the personnel why preventive maintenance is being started, how it will function, what each employee's part will be, what records are to be used, and how they are to be used. In other words, training also includes selling the program to the personnel.

Inspections and Services

Systematic and periodic inspections and servicing is the heart of the preventive maintenance program. Maintenance inspections and services are made at specified intervals. Every piece of equipment and every structure is inspected, faults are noted, and corrections are made on an established schedule based on predetermined frequencies. The inspections and services extend from the basic maintenance procedures of checking for cleanliness, excessive heat, vibration, lubrication, and leaks to complete disassembly of the equipment on a periodic basis.

Record System

The backbone of the whole system is a record of inspections and services to be performed and the actual work performed. This part of the program is the hardest to sell to the personnel performing the maintenance, but is



WD AGO FORM 5-34 — UTILITIES INSPECTION AND SERVICE RECORD

Equip. No. 7673-35.11-1 — Description N.S. FILTER DISTRIBUTOR, AMER WELL, MOTOR-DRIVEN

Preventive maintenance to be done by: SEWAGE PLANT DAY-SHIFT OPERATOR, JOHN DOE

Item No.	Work to be done	Reference	Frequency	Time
1	CLEAN JETS	63 a	DAILY	
2	FLUSH ARMS	63 b	"	
4	CHECK AIR-RELIEF PIPE	64 b	"	
50, 51	CHECK MOTOR CONDITION	14 a & b	"	
5	LUBRICATE OIL SEAL AND GUIDE BEARING	64 c	WEEKLY	MONDAY
10	CHECK OIL LEVEL IN REDUCER	58 a	"	"
6	LUBRICATE MAIN THRUST BEARING	64 a	MONTHLY	1ST MONDAY
7	CHECK FOR EXTREME SURGES	64 h	"	"
20, 30	CHECK TENSION AND ALIGNMENT (V-BELT DRIVE)	16 b	"	"
53	CHECK GREASE IN MOTOR BALL BEARINGS	14 a (1)	"	"
8	CHECK FREEZEOUT PLUG	64 f	QUARTERLY	NOV., FEB. MAY, AUG
3	ADJUST ARMS	63 a	SEMIANNUALLY	MAY, NOV.
5 a	CHANGE OIL IN REDUCER	58 a	"	" "
11	CHECK BRUSHES AND CLEAN COLLECTOR RINGS	64 i	"	" "
12	CHECK COUPLING ALIGNMENT	19 b	"	" "
54	FLUSH ANTIFRICTION BEARINGS	14 d	"	" "

Schedule inspection and service on this side. Record inspection and service on reverse side.

(1)

SERVICE RECORD

Date	Work done	Signed	Date	Work done	Signed	Date	Work done	Signed
1/3/55	1, 2, 4, 50, 51, OK	JD	1/26	1, 2, 4, 50, 51, OK	JD	2/24	1, 2, 4, 50, 51, OK	JD
1/9/55	" " " " "	JD	1/26	" " " " "	JD	2/15	" " " " "	JD
1/10	" " " " "	JD	1/27	1, 2, 4, 50, 51 OK	JD	2/16	" " " " "	JD
1/11	" " " " "	JD	1/28	" " " " "	C.C.	2/17	" " " " "	JD
1/12	" " " " "	JD	1/29	5, 10 DONE	JD	2/18	" " " " "	C.C.
1/13	" " " " "	JD	"	1, 2, 4, 50, 51 OK	JD	2/19	1, 2, 4, 50, 51 OK	JD
1/14	" " " " "	C.C.	1/30	" " " " "	JD	"	5, 10 (ADDED OIL)	JD
1/15	1, 2, 4, 50, 51 OK	JD	1/31	" " " " "	JD	2/20	1, 2, 4, 50, 51 OK	JD
"	5, 10 DONE	JD	2/1	" " " " "	JD	2/21	" " " " "	JD
1/16	1, 2, 4, 50, 51, OK	JD	2/2	" " " " "	JD	2/22	" " " " "	JD
1/17	" " " " "	JD	2/3	" " " " "	JD	2/23	" " " " "	JD
1/18	" " " " "	JD	2/4	" " " " "	C.C.	2/24	" " " " "	JD
1/19	" " " " "	JD	2/5	K, 16, 6, 7, 2a, 3a 53		2/25	1, 2, 4, 50, 51 OK	C.C.
1/20	" " " " "	JD		1, 2, 4, 50, 51 OK	JD	2/26	1, 2, 4, 50, 51, 5, 10 OK	JD
1/21	" " " " "	C.C.	2/6	" " " " "	JD	2/27	1, 2, 4, 50, 51 OK	JD
1/22	51, VIBRATION RPTD		2/7	" " " " "	JD	2/28	" " " " "	JD
	10 POST ENGR	JD	2/7	1, 2, OK 4 LUBRICATED		3/1	" " " " "	JD
"	1, 2, 4, 50 OK	JD		50, 51 OK	JD	3/2	" " " " "	JD
"	5, 10 DONE	JD	2/9	1, 2, 4, 50, 51 OK	JD	3/3	" " " " "	JD
1/23	1, 2, 4, 50 OK	JD	2/10	" " " " "	JD	3/4	1, 2, 4, 50, 51 OK	C.C.
1/24	ABOVE OK. ELECT		2/11	" " " " "	C.C.	3/5	1, 2, 4, 50, 51, 5, 10 OK	JD
	REPAIRED MOTOR	JD	2/12	1, 2, 4, 50, 51, 5, 10 OK	JD	"	6, 7, 2a, 3a, 53 OK	JD
	W.O. 220	403	2/13	1, 2, 4, 50, 51 OK	JD	3/6	NO SIGNED CARD	JD

(2)

Fig. 1—TYPICAL service card record card for utilities equipment inspection.

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equally essential to the program. The operator usually abhors any form of paper work. Complex records bewilder and discourage the personnel, use up too much of their time, cause them to lose confidence in the program, may lead to falsifying of records, and may eventually result in a beautiful set of records that are serving no useful purpose.

The record system should be simple, but it must be adequate. The records are management tools. Small plants can get along adequately with one record card and supplemental data whereas large plants with a greater number of personnel may effectively use more than one record card. Large plants have a better opportunity to analyze the records, to determine when it is economically justifiable to replace equipment, or whether faults in design, materials, or installation are causing excessive maintenance costs.

The record system employed in the Air Force utilizes one record card (Figure 1). Separate forms are usually made out for each major separate piece of equipment, including accessories needed to operate it. Thus, the card for a sewage pump includes pump, motor, and float control. If inspections and servicing operations on a separate card is prepared for one or more components of the unit.

With reference to Figure 1, the procedure for filling out the form is as follows:

1. Equipment number. Each piece of equipment is given an identification number. The number shows the building or structure in which the equipment is located and makes it possible to distinguish between a number of identical units located in the same building.

2. Description. The equipment is described briefly but in enough detail so it can be identified readily.

3. Preventive maintenance to be done by. The job title and name of the person responsible for maintenance is shown. Where operators perform maintenance this should be the person who actually operates the equipment.

4. Item number. This refers to item numbers in an Air Force manual used to guide the personnel in maintaining the equipment. It has no practical use for civilian plants. Manufacturer's instructions for maintenance can be used as a guide and a reference number system utilized to refer to them.

5. Work to be done. This is a short statement of the work that the person performing the maintenance will have to do. This column acts as a check list for the person performing the maintenance and gives him specific duties so that there is no doubt about what he is supposed to do.

6. Reference. This also refers to the previously mentioned manual and has no practical use for civilian plants.

7. Frequency. Frequencies of operations are established, based on local experience and that of the equipment manufacturer. Frequencies may be reevaluated after the system is under way by reviewing the cards. After the program is rolling along it may be found that frequencies should be extended, as evidenced by a fewer number of corrections being required.

8. Time. The time column shows the specific day or month service is due. Quarterly, semiannual, and annual inspections can be staggered to prevent rush periods and conflicts in schedule. The season should be chosen when work can be done best.

9. Service Record. On the back of the card, the date, item number, and initials are recorded whenever maintenance is performed. If service needed is beyond the capabilities of the inspector he requests skilled help and enters the request in the "work done" column.

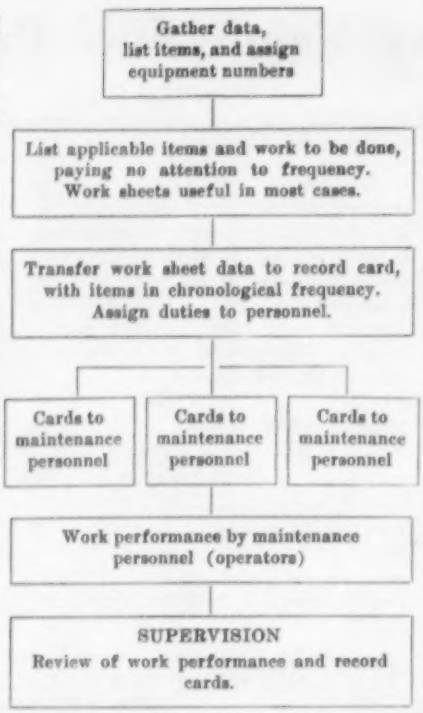

Gather data, list items, and assign equipment numbers
List applicable items and work to be done, paying no attention to frequency. Work sheets useful in most cases.
Transfer work sheet data to record card, with items in chronological frequency. Assign duties to personnel.
Cards to maintenance personnel
Cards to maintenance personnel
Cards to maintenance personnel
Work performance by maintenance personnel (operators)
SUPERVISION
Review of work performance and record cards.

Fig. 2—FLOW diagram of card record handling for preventive maintenance.

Supervision

One of the failings of some preventive maintenance programs is lack of supervision. Too often a program is started and then left to run itself. That is poor management in any business. The supervisor must start the program and then follow it up continuously by praising maintenance personnel when credit is due, spot-checking equipment and records, analyzing the maintenance performed and equipment failures to evaluate the results of the program, and reviewing the program from time to time in order to improve it. Personnel should be kept informed of the over-all results of the program so that they can see and understand where they are reducing breakdowns and costs.

Starting the Program

If it is planned to start a preventive maintenance program, management should first sell itself on the program completely. The responsible party should then plan it thoroughly and study all of its ramifications until it is known frontwards and backwards.

A survey should be made of all of the equipment in the plant and data gathered from the name plates. These data will be placed on the record cards and used to order manufacturer's maintenance and operation instructions not already available at the plant. Approximately 40 to 50 cards are required for a sewage plant serving an Army or Air Force base of approximately 35,000 residents. Examples of equipment and the cards required are as follows:

Equipment	No. of Cards
Grit chambers	½
Sluice gates, several at same location	1
Comminutor	1
Settling tank, including sludge collectors	2
Pump and motor	1
Venturi meter	1
Gas chlorinator	1
Valves, several at same location	1
Trickling filter	1

The large sewage and industrial waste plants may find it advisable to use a duplicate set of inspection and servicing record cards, as the Air Force and Army do. When this method is used one set of cards is given to the personnel who perform the work and the master set is kept in the office. At the beginning of the month the operator's cards are turned in to the supervisor. Entries are checked to insure that all work was accomplished and a summary of entries is transferred to the master file. The summary includes any special difficulties encountered by the operator, work orders required for maintenance, and a consolidated entry of items checked.

Small plants will find that the supervisor can use the operator's cards to do his checking and analyzing of the program and will not require a duplicate set.

Summary

Preventive maintenance offers a planned program for keeping major repair troubles from developing, for it is the "little things" left unattended that can grow into big problems. It has proved itself in all types of industries.

Elements of a good preventive maintenance program include:

1. Training of the personnel until they know their job.
2. Systematic and periodic inspection and servicing.
3. Assignment of specific responsibilities.
4. Supervision of the program.

A record system of the inspections and servicing is necessary, but it should be simple. The record card described herein can be modified to meet local conditions. If the record system does not serve a useful purpose it is a waste of time; however, if it does not serve a useful purpose usually something else is wrong with the program. Figure 2 is a flow diagram of the record card procedures from gathering the data to be placed on the card to final review of the cards by the supervisor.

Preventive maintenance is not a cureall for all problems of maintenance at a sewage or industrial waste plant; yet it will go a long way in solving the problems.

Discussion of "Preventive Maintenance Practices"*

by KERWIN L. MICK

Chief Engr. and Supt., Minneapolis—Saint Paul Sanitary District, St. Paul, Minn.

In his excellent paper Colonel Sanders has illustrated the benefits to be realized from the practice of preventive maintenance in any sewage treatment plant, with special reference to the United States Army and Air Force installations.

It is gratifying to see how well preventive maintenance practice at the Minneapolis-Saint Paul plant fits in with the ideas presented. This discussion, therefore, is devoted principally to preventive maintenance at Minneapolis-Saint Paul to further illustrate the points brought out in the paper.

At the Sanitary District, careful records are kept of all maintenance work and parts required in order to compare wear and life of the equipment and to facilitate the ordering and stocking of vital spare parts. The District currently has a 15-man maintenance department consisting of a maintenance engineer, a shop foreman, two electricians, five machinist-mechanics, one machinist's helper, three repairmen, one pipefitter, and painter. These men work the day shift only (5-day week), except when called down to the plant for emergency repairs. Such emergency calls are held to a minimum by a program of preventive maintenance. Along with the Maintenance Department, the operating staff also plays an important part in this program. In fact, two utility operators spend the major portion of their time on preventive maintenance work, particularly on the more complicated pieces of equipment, making adjustments, greasing, etc.

In addition to the work of these two utility operators, each operating shift is assigned a definite list of equipment and areas in the plant to keep clean, adjusted, greased, and inspected for good operating order at all times. The greasing chart in the plant shows just what pieces of equipment each shift is responsible for and the frequency for performing the greasing operations.

In addition, there is a card system to remind the plant operators of various jobs to be done at more or less irregular intervals. Figure 1 illustrates a sample card of this nature. These cards are kept in a file in the office and twice a month those cards which are due for action are withdrawn and placed on the plant operator's desk. The file clerk retains a duplicate of each card withdrawn so that she may check to see that the card is returned within a reasonable time; in other words, to insure that the work has been done.

Typical operations, for each of which a card is maintained, include monthly opening and closing of seldom-used valves; quarterly check of the air lock gates, seats, air filter bags, etc., in the pneumatic conveyor for dry chemicals; and monthly turning over by hand of spare units of moving equipment such as the blowers and vacuum pumps for the sludge vacuum filters. As another example, each shift is assigned by card two grit chambers to drain down and inspect the grit collectors and washers once a month.

The electricians have a regular schedule for checking and overhauling of electric motors, motor controls, and relays. There are more than 300 motors in the plant, ranging up to 75 h.p. in size, and about 400 circuit breakers. The scheduled frequency of overhaul depends upon the usage of the motor.

For any repair work which has to be done by the maintenance crew, a maintenance order (Figure 2) is initiated by the plant operator, after which it must be signed by the maintenance engineer and the chief engineer. The maintenance order shows the name, location, and code number of the equipment, and a brief description of the work believed to be necessary. The order also contains space for the accounting department to record the amount of labor and materials used on the repair job. Each piece of equipment has a code number, which in itself identifies the equipment as to location, type, and item number.

In the average year, more than 900 of these maintenance orders are completed. At the close of each week, there is prepared a typewritten list of all outstanding maintenance orders not yet completed, and another list of the orders completed during the preceding week. After the close of each month, there is prepared a typewritten list of all jobs completed that month, giving the date, job number, work done, and labor and material costs. These lists are distributed to the maintenance engineer and the plant operator in charge of each shift so that they may keep abreast of the status and cost of all the maintenance work.

A few other typical examples of preventive maintenance work may be of interest:

*Reprinted from *Sewage and Industrial Wastes*, Vol. 26, p. 334, by permission of FSIWA.

The settling tanks at the Minneapolis-Saint Paul plant contain approximately 5½ mi. of sludge collector chain, with 1,500 sludge scrapers of redwood or fir. There is approximately $70,000 worth of chain in these tanks. The original chain is still in use on the longitudinal sludge collectors after 15 years of service. Preventive maintenance is largely responsible for this long service record. Measurements have been taken from year to year of the wear on the barrels of the chain. Before it is worn through to the pins, the chain is turned over. Between 1950 and 1953, the chain was turned over in all six settling tanks. The material cost for new chain in each tank would be approximately $10,000, whereas the material cost to turn the chain over (new attachment links) is only about $1,000. When the chain is turned over, the sprockets are built up by welding with Ni-rod to conform to the original tooth shape. Two strips of stellite (very hard cobalt alloy) are applied to each of the main wearing shoes. This can be done without draining down the tank. Occasionally it is necessary to weld new wearing strips on the rails in the tank bottom. This is more economical than the replacement of wearing shoes, which would otherwise be necessary if the stellite was not used. Each settling tank is pumped down and inspected once a year. This type of chain preventive maintenance is also done in the sludge concentration tanks and in the grit chambers.

Another example of preventive maintenance is found in the sludge pump pistons and packings. The Maintenance Department piped water to the top of each sludge pump piston through a small copper tube to insure lubrication of the pistons and packing and thus reduce the wear. Chevron packing installed in these pumps has given seven years of service to date and is still in use. Other types of packing have lasted from one to three years.

Another type of preventive maintenance is illustrated by the installation of bulkheads in the Minneapolis underground Venturi meter vaults to close them off from a section of open sewer. Formerly these vaults and their equipment were dripping wet, with resultant heavy corrosion and electrical failures. With the aid of the bulkheads and a small ¼- to ½-hp. ventilating fan installed in each vault, the latter are now maintained in a dry condition, free from excess moisture and objectionable sewer gases.

The installation of a small ventilating fan in another underground vault containing an electrical control panel likewise has eliminated the rapid corrosition which formerly prevailed there.

At the Minneapolis-Saint Paul Plant the maintenance cost has averaged approximately 14 per cent of the total cost of operation and maintenance for the past 12 years; it is currently running between 15 and 17 per cent, gradually increasing as the plant gets older.

Code No. 4-12.1

Description of Equipment:- Garage Doors

Work Assigned to:- Shift "C" Building Operator
Screen & Grit Chamber Bldg.

	Jan.		July		Weekly		
	Feb.		Aug.		Monthly		
x	Mar.	x	Sept.	x	Quarterly		
	Apr.		Oct.		Semi-Ann.		
	May		Nov.		Annually		
x	June	x	Dec.				

Assign. No.	Work to be Done	Frequency	Date	Reference
	Inspect lifting cables on doors	1 mos.	1st	

SERVICE RECORD

Assign. No.	Date	Work Done and Remarks	Signed

Fig. 1—EXAMPLE of service record inspection card.

MINNEAPOLIS-SAINT PAUL SANITARY DISTRICT

MAINTENANCE ORDER **№ 15145**

DEPARTMENT Filtration & Incineration Bldg. DATE Jan. 31, 1953

EQUIPMENT Filter #1

JOB TITLE Replace Screens

DESCRIPTION

Replace end strips if needed.

Replace drainage strips if needed.

Replace division strips if needed.

Dowel division strips.

CODE 2-26.1 (M) C MC Mr. Trulander, Plant Operator

ESTIMATED COST $

COMPLETED COST $ John C. Sager, Engineer Maintenance and Design

COMPLETED Jan. 31, 1953 K. L. Mick, Chief Engineer

ACCOUNTING

LABOR Date	LABOR Amount	MATERIAL Date	MATERIAL Reference	MATERIAL Amount	Date	Reference	Amount
1-31-53	44 03	1-31-53	R 19510	20 24			
2-28-53	407 86	1-31-53	R 19522	16			
	451 89	1-31-53	R 19538	212 26			
		1-31-53	R 19549	8 31			
				240 97			

Fig. 2—TYPICAL maintenance work order filled out.

V. WATER WORKS OPERATIONS

THERE IS plenty of water for all the uses and needs of mankind. Unfortunately, it is not always at the location where it is needed most. The Mississippi River system carries off billions of gallons of unused water daily. Through the Great Lakes system pass more billions of gallons of water each day. Down the Columbia, the Colorado and the great rivers of Canada likewise flow more billion gallons each day. And yet there are vast areas where there isn't enough water for agriculture, industry, or even community life. One of the biggest problems of the water works man is to obtain an adequate supply for the domestic and industrial needs of his community.

Source of Supply

Water is found in the atmosphere, on the surface of the earth and below the surface of the earth. Water in the atmosphere is precipitated and falls to the earth, where it collects in lakes, ponds and rivers that run to the sea, or it sinks into the ground where it is stored or used by vegetation which returns it to the atmosphere. Water from the seas evaporates to help replenish the supply in the atmosphere. Water in the atmosphere and in the seas is not usable directly by man.

Man must obtain his water from fresh surface waters or from the ground. The development, maintenance and protection of water supplies are important functions in water works operations. The supply must be adequate; it must be of a quality that can be treated; and it must be protected against undue contamination. The procurement of water looms large as a problem for water works managers.

Distribution

Of what use is water if it cannot be placed where man wishes to use it? It is the function of a distribution system to deliver water to its point of use. This system will include pipes or conveying conduits that bring water from its source to the consumer. It is customary to refer to a distribution system as the network of pipes and appurtenances which carry the water from a treatment plant or pumping station throughout the community served. Transmission main is the term usually applied to large conduits which carry water from a distant source to a treatment plant or distribution system.

Included as an important part of water works operations are the design, construction, maintenance and operation of transmission mains and distribution systems, including pipes, valves, fire hydrants and storage tanks, either elevated or at ground level. Design will be concerned with proper sizing for desired carrying capacity; construction with main laying; maintenance with prevention or remedies for loss of carrying capacity, tuberculation and corrosion; operation with service connections, meter installations and meter reading. No matter what the size of a community the distribution system is a highly important part of the water works.

Treatment

When the available supply of water is not free of undesirable constituents it must be treated before use. The kind of treatment processes used depends on the nature of the undesirable constituents to be removed. Small amounts of suspended matter can be removed by long sedimentation periods in reservoirs. When waters are more turbid due to relatively large amounts of suspended and colloidal matter, chemicals are added to coagulate the turbidity and sedimentation is provided to allow for natural removal of most of the coagulated turbidity. Filtration through sand will remove practically all of the remaining turbidity.

Bacteria are removed largely by coagulation, sedimentation and filtration. Such bacteria as are not removed by these treatments can be killed by disinfection with chlorine or other agents. Tastes and odors may be removed by treatment with activated carbon or chlorine and sometimes by aeration. If tastes and odors are due to microscopic growths they may be controlled by treatment to kill the organisms.

If the constituents which make water undesirable are dissolved minerals, chemical treatment known as softening is used to remove the offending minerals which are the salts of calcium and magnesium. If iron or manganese are present in undesirable amounts, they too are removed by chemical treatment.

These use of these treatment processes to improve the quality of water is commonly termed water purification, regardless of the number of processes employed. Nearly all water supplies are subjected to disinfection if only as a precautionary measure. Most surface water supplies are coagulated, settled and filtered as well. Some surface and well supplies are softened.

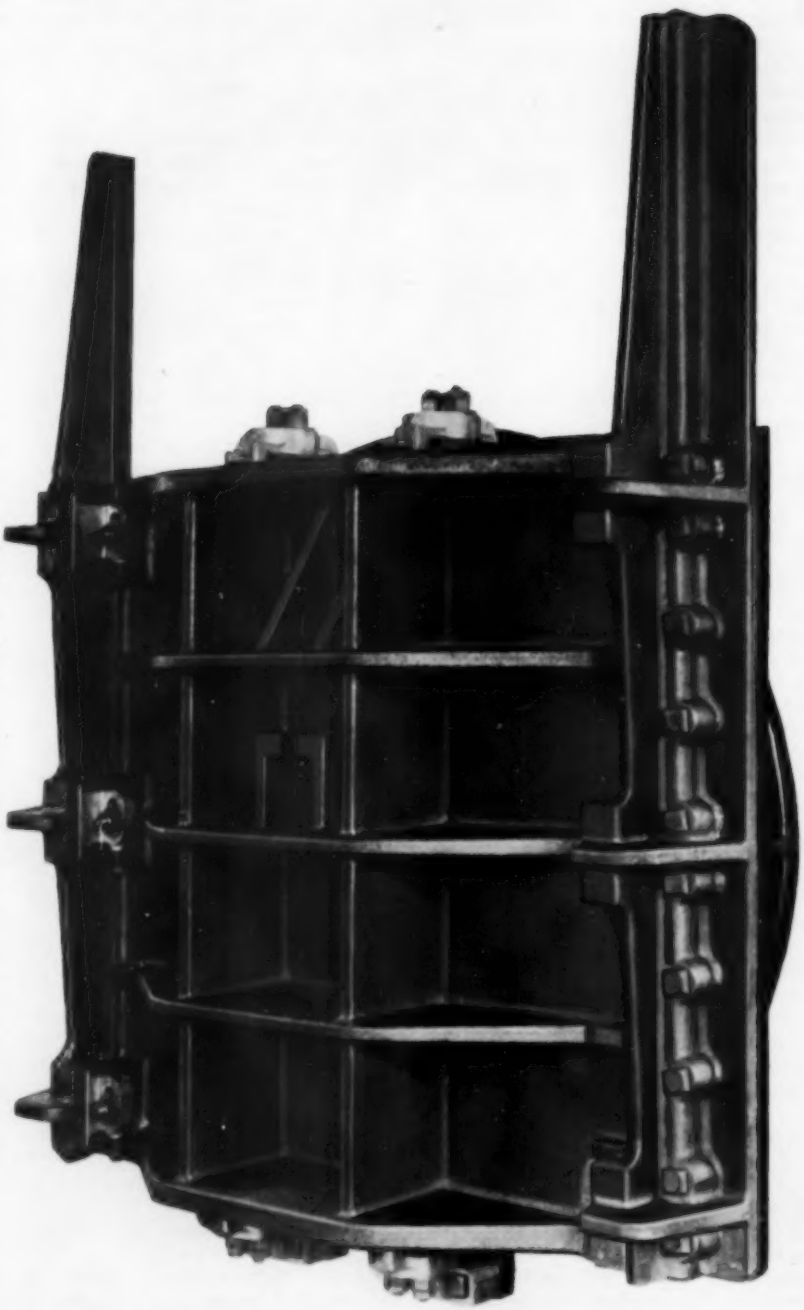
Water purification or treatment is a function of water works operations that require both skill and knowledge. Coagulation, sedimentation and filtration are frequently discussed together, as water purification or treatment. On the other hand, three processes in water treatment are of sufficiently disrelated character that they are treated as separate topics in any discussion of water works practices. These are (1) chlorination, (mainly employed for disinfection), (2) softening, which includes the lime-soda process and the ion-exchange process, and (3) iron and manganese removal.

Other Operations

Other operations in water works include, of course, pumping, flow measurement, instrumentation and control, chemical handling and feeding, coagulation and sedimentation, corrosion control, laboratory control, and maintenance. These are all functional operations that apply to both water and sewage works operations. Material on each of these operations has been presented and discussed in Section IV of this Reference & Data Data Edition of Water & Sewage Works.

FILER & STOWELL SLUICE GATES

MANUAL ELECTRIC OR CYLINDER OPERATED



The sturdy design of Filer & Stowell Sluice Gates furnish long trouble free service. Where the conditions are tough, F & S Gates have earned their reputation for unsurpassed ruggedness, continuous and low cost operation.

They are fully bronze mounted: including bronze seats on the frames and gate leaves and adjustable side wedges; also top and bottom wedges when required by operating conditions.

Filer & Stowell Sluice Gates are available in all standard sizes and also special sizes or designs to meet your unusual conditions.

Consult Bulletin 753 for complete data and specifications.

THE FILER & STOWELL COMPANY

147 E. BECHER STREET, MILWAUKEE 7, WISCONSIN

SOURCE OF SUPPLY

RAINFALL in the United States averages 30 inches a year, equal to 432,900,000,000,000 gals. per year. Some of this water enters the ground and returns to the atmosphere by transpiration through vegetation. Some of the ground water returns to the surface. Some of the surface water evaporates directly, most of the rest returns to the ocean reservoirs. The accompanying diagram shows what happens to precipitation; values are expressed as percent of total and are approximate.

Diagram showing what happens to rainfall

Surface Supplies

The quality of surface water depends on the area and character of the watershed including its geology, topography, domestic development, time of year, etc.

Streams are more variable in content than ponds or lakes. Streams consist of direct runoff, overflow from lakes, or seepage from high ground. Pollution of streams may be natural (turbidity, color, odor, organic matter, dissolved solids) or man made (sewage and industrial wastes). There are 15 major drainage basins in the United States, each with its own quality characteristics.

Impounding reservoirs are basins created by damming a surface stream to store runoff from the watershed. The *yield* of a reservoir is the total precipitation on a watershed, less the evapo-transpiration. Yield is calculated in gallons per year or per day. *Safe yield* is the minimum yield recorded or expected under the most adverse rainfall conditions. *Draft* is the quantity of water that will be drawn for actual use. The function of a reservoir is to store water from high flow for use during periods of low precipitation and runoff.

In planning for an impounding reservoir careful consideration must be given to the required capacity, the possibility and effect of siltation, and the effect of storage on water quality. Other problems include those of public health and flood control and the construction and operation of the impounding dam.

Ground Water Supplies

Ground water occurs in aquifers principally in sedimentary porus materials, buried river valleys or beds of ancient lakes, glacial deposits, and caverns in limestone districts. Sands, gravels and sandstones furnish most of the ground water supplies in the United States.

The quality of ground water depends on the material through which the water passes and the solvent action of the water on that material. Bacterial pollution is usually absent in ground water except in some cases where pollution from above the surface is discharged below the water table or reaches the aquifer through crevices in the overlying earth cover. Ground water is usually clear cold, colorless and is often hard due to dissolved salts of calcium and magnesium. Temperature is usually constant and for wells 30 to 60 ft. deep is generally a few degrees above the average annual temperature for the region.

Underground supplies may be springs, shallow wells, infiltration galleries, or deep wells. The Ranney Water Collector is a "water mine," a combination of a central dug well with radial driven wells at its bottom.

The location of wells by divination or dowsing is considered to have no basis in scientific fact, but is still popular with individual well owners. Other more scientific methods of well location include the geological approach and geophysical prospecting.

In the location of wells, consideration must be given to sanitary conditions existing on the surface and the wells must be properly spaced to avoid interference. The construction of wells depends on depth, and the type of strata into which the well is sunk.

Important to water works operators of ground water supplies is the proper development of well capacity. Development is the term applied to methods for increasing the yield of a well when it is constructed. Methods used for developing sand wells include surging. Rock wells may be surged, blasted, or wire brushed.

Well pollution, operation and maintenance are the particular concern to the operator of a well. Pollution may include sewage, industrial waste, garbage and ashes and salt water. Particularly important in coastal areas is salt water intrusion.

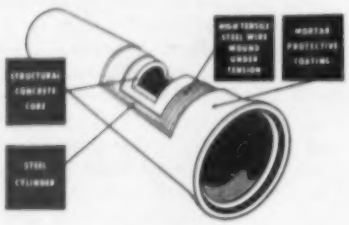
Operating problems include shortage of supply or sand in the water. Disinfection should be practiced as a matter of precaution. Operating procedures should include complete records on pumping levels, drawdown measurements, recovery levels, and pump operation. Recharge of depleted aquifers may be by artificial methods, spreading, return wells, recharge wells, or even sewage reclamation.

Maintenance is the term applied to procedures for maintaining or restoring capacity or production of a well that has decreased in output over a period of use. Methods used for maintenance include reducing pumping rates, lowering of pump bowls, cleaning clogged screens by surging, acidizing, chlorination or calgon treatment. Wells that can not be restored in capacity are usually abandoned.

PRESTRESSED CONCRETE STEEL-CYLINDER PIPE

AWWA Spec. C301-52

PRICE BROTHERS COMPANY, P. O. Box 825, DAYTON 1, OHIO



Prestressed Pipe was designed by research and structural engineers from a *combination* of materials, each to do a specific job, and to provide a *combination* of advantages found in no other pipe.

A *steel cylinder* to provide water tightness and high beam strength.

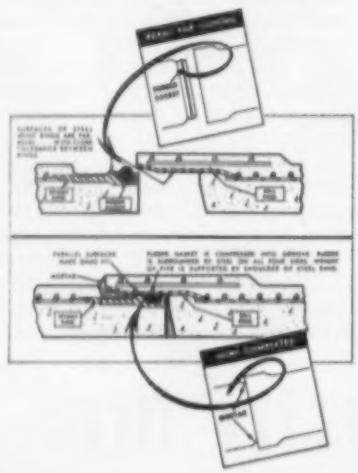
A *centrifugally spun* structural concrete core to give permanent and sustained high flow without tuberculation or corrosion.

A wrapping of *high tensile steel* wire under tension to prestress the steel cylinder and concrete core thus permitting high pressure without tension in these materials.

A rubber and zinc coated steel *expansion joint* to provide flexible, watertight connections.

An outside encasement of *rich cement mortar* to protect the entire waterline.

FLEXIBLE, WATERTIGHT JOINT



HOW PRESTRESSED CONCRETE STEEL-CYLINDER PIPE MEETS THE REQUIREMENTS FOR A WATER LINE

LIFE EXPECTANCY

SOIL ACTION—On Price Prestressed Pipe only concrete is exposed both inside and out. Concrete is "at home" in the ground. It cannot rust or corrode, and almost always actually gets harder and stronger the longer it is underground. Underground concrete water lines in Mexico and France are still in excellent condition after hundreds of years.

ELECTROLYSIS—Price Pipe has never been affected by electrolysis.

STRENGTH

BEAM STRENGTH—The steel cylinder encased inside Price Pipe and the structural concrete core provide an exceptionally high beam strength.

BURSTING STRENGTH—The combination of a steel cylinder, prestressed high tensile steel wire and concrete make Price Pipe shatterproof. Sudden and complete failure or bursting is all but impossible.

GALLONS OF WATER DELIVERED

INITIAL RATE OF FLOW—With Prestressed Pipe, water flows over concrete, which equals the highest flow coefficient of *any* pressure pipe structural material.

LONG TERM RATE OF FLOW—Concrete not only retains its high "C" value, it often increases because of a slippery surface that forms on the concrete. Tests in Louisville show an increase from a "C" of 145 in 1931 to a "C" of 149 in 1948. Tests in Denver show an increase from 141 in 1925 to 150 in 1943.

TUBERCULATION AND CORROSION—Under ordinary circumstances Price Pipe will never corrode or tuberculate. After years of service, it will have exactly the same diameter and be just as smooth as when installed.*

JOINTS—The rubber and zinc-coated steel joint on Price Pipe is *flexible*. It can adjust to expansion, contraction, vibrations and settling without leaking even with high internal pressures.

MAINTENANCE

CLEAN OUT—Price Pipe will neither tuberculate or corrode, and will require no cleaning out.

RELINING—The structural concrete core of Price Pipe serves as its lining. It is held in compression by the wrapping of high tensile steel wire and is an integral part of the pipe. It does not chip or disintegrate. Relining is never required.

BLOW UPS—Blow ups and resulting floods are all but impossible with Price Pipe. Its design makes it shatterproof.

TAPPING — Any water-works serviceman can tap Price Pipe, under pressure, using regular type, long travel tapping machine, with a carboloy tipped cutter. The design of the tap actually makes the pipe *stronger* at the point of the tap.

COST

ORIGINAL COST—Price Pipe, in spite of its long life, sustained capacity and great strength costs no more than other types of water pipe. Under certain conditions it may even be considerably less.

INSTALLATION — On most installations a back hoe both digs the trench and lays Price Pipe, resulting in speed and low cost. This is because of the self-centering joint on which steel takes the backload and rubber forms the seal. Contractors generally bid lower on the installation of Price Pipe than any other type of water pipe.

PUMPING COSTS — Price Pipe's flow coefficient *stays* high and the bore stays smooth. Pumping costs do not rise as they do with some pipes.

LONG TERM COST — Here's where Prestressed Pipe really shines. Add to low original cost the advantages of no clean-outs, no relining, no blow ups, absolute minimum leakage, and lower pumping costs, plus the permanency of concrete . . . then you have *true* economy.

YOUR REQUIREMENTS

PRESSURES—Prestressed Pipe can be designed for any pressure common to American waterworks practice with adequate reserve strength for normal overloadings.

SPECIALS — Connections and fittings are readily available. They are manufactured of reinforced concrete and custom tailored to the design requirements.

SIZES—Prestressed Pipe is available in 16-foot lengths and in diameters of 16", 20", 24", 30", 36", 42", 48" and larger.

DELIVERY — Price Pipe is available from plants in Dayton, Ohio, and Miami, Fla. On large jobs a portable plant can be set up on the job site.

OTHER TYPES OF CONCRETE PIPE—Price Brothers Co. also manufactures Concrete Steel Cylinder Pipe, Not Prestressed; Subaqueous, Sewer and Culvert Pipe.

INFORMATION — Price Brothers engineers know pipe line problems. They will be glad to help in any way they can, without obligation. For booklets on Manufacture, Laying and Tapping, write Price Brothers Co., P. O. Box 825, Dayton 1, Ohio. For general information mail the Reader Service Card.

* In isolated instances, but not common in America; algae and sponge formations will collect on the inside of all types of water lines. Rare soil conditions may affect the permanence of *any* pipe material.

A Completely Adequate Source of Supply

by FRANCIS S. FRIEL
Consulting Engineer
Philadelphia, Pa.

From a Symposium of Papers on Water Service and What It Costs

Mr. Friel's is the second of four papers comprising a symposium on "Water Service and What It Costs" presented at the Annual Meeting of the Pennsylvania Water Works Association in Atlantic City, N. J., in October, 1954. The other three were published in the magazine section of WATER & SEWAGE WORKS. They are:

What Constitutes Reasonable Water Service
Completely Adequate Water Treatment
A Completely Adequate Distribution System

THIS discussion will summarize problems relating to the development of satisfactory sources of water supply, both surface and underground, and will then discuss approximate construction costs of developing the two types of supplies. It must be borne in mind that each water supply undertaking is a problem in itself—and that no definite yardstick can be set up which will accurately estimate the cost of all types of water supplies.

The unit cost of developing a water supply from a large river, such as the Delaware, is considerably less than that for developing a supply from an inland stream where it is necessary to construct a dam and an impounding reservoir. The cost per gallon of developed water yield of an underground source is less in an area where the subsurface is sand, such as areas in New Jersey, than it is in a rock formation which is usually encountered in most parts of Pennsylvania. Other factors which bear upon the cost of a completely adequate and satisfactory source of water supply are the distance of the supply from the filter plant or distribution system, and also whether the water requires pumping or flows to the point of usage by gravity. Therefore, the estimated costs which are presented in this discussion should be used with caution.

In the development of these cost data, a completely adequate and satisfactory source of supply has been considered as one which will produce water of proper quality in satisfactory quantities for both domestic and industrial purposes. The water must be potable or capable of being made potable by treatment. The municipality or industry which can obtain a potable supply from surface waters without treatment, other than chlorination, is rare and fortunate indeed.

Planning for Future Growth

An adequate supply must provide for the future growth of both population and industry. Where new supplies are being considered, the projected demands on the system should be estimated for a period of at least 25 years in the future—and future forecasts should be reviewed from time to time, possibly each year. It is prudent to overestimate demands rather than to underestimate, especially where it is economically feasible to provide for surface water which will make possible industrial growth and increased domestic usage.

Past experience indicates that many supplies are inadequate. L. D. Matter reported[1] that during 1953, 56 public water supplies in Pennsylvania were dangerously low; as a result, restrictions were placed upon the use of water for such purposes as car washing and lawn sprinkling. Of these 56 supplies, 21 found it necessary to obtain water from auxiliary or emergency sources continuously through the 1953 dry period and until April, 1954. The communities which were affected ranged in population from 500 to 80,000. The cause of these water shortages was the increased water demand coupled with the dry season and subsequent low stream flows.

C. G. Paulsen[2], in discussing the report of the U. S. Geological Survey on "Public Water Supply Shortages—1953" has presented statistics on the number of water shortages due to drought and supply failures or other causes, as 1,072, or 6.2 per cent of all systems reporting.[3] The data in Table 1 are from this report.

Increased Demands Cause Shortages

It is of interest to note that 38 per cent of the systems serving over 100,000 population were faced with water shortages; and that 30 per cent of the systems serving populations between 50,000 and 100,000 persons had the same experience. It is further significant that 51 per cent of the 1,072 cases of water shortage were caused by population growth and increased seasonal use.

There has been a sharp rise in the use of water not only in Pennsylvania, but all over the country—and failures in certain water supply systems have been inevitable because of the great demands made upon them. These failures are accentuated in seasons when droughts are widespread, such as occurred in the Summer of 1953, and which have continued to the present.

TABLE 1

Public Water Supply Shortages—1953

Population Group	No. of Systems Reported	No. of Shortages	Systems Experiencing a Shortage
Less than 1,000	8,433	349	4.1%
1,000 to 5,000	6,047	371	6.2%
5,000 to 10,000	1,126	130	12.0%
10,000 to 25,000	719	86	12.0%
25,000 to 50,000	221	34	15.0%
50,000 to 100,000	108	32	30.0%
More than 100,000	93	35	38.0%
Population unknown		35	
TOTAL	16,747	1,072	6.4%

This discussion of water shortages has a direct bearing upon the cost of a fully adequate and satisfactory source of water supply, because it is necessary to consider the basic elements of design which contribute to failures, and which should be provided for in an adequate system. The reconnaissance by the U. S. Geological Survey, of the 1,072 systems which reported water shortages, revealed that a water supply was assumed to have a shortage when it was unable to supply its customers' peak demands and was compelled to restrict the use of water.

Another example: early in 1953, *Public Works Magazine*[4] made a questionnaire survey of water works supplying a population of more than 3,000. This survey revealed that these shortages were grouped into:

(a) Those due to an inadequate water supply,

(b) Those due to inadequate treatment facilities, and

(c) Those due to inadequate distribution facilities. Fifty-five per cent of the shortages as reported by this survey were attributed to demands exceeding water supply.

Generally speaking, about 6 per cent of all public water supply systems in the United States, serving about 24-million customers, restricted the use of water in 1953. For all shortages reported, the predominant reason was due to inadequate water supply, increased population and seasonal variation and use. Of the 1,072 shortages reported to the U. S. Geological Survey, drought or failure of the water supply alone counted for 367 and contributed to an additional 116.

It is pertinent to this discussion to note that water withdrawn from surface supplies in Pennsylvania in 1951[5] for public supply purposes was 1.2 billion gallons per day, while that taken from sub-surface supplies was 112-million gallons per day. More than 90 per cent of the water used in Pennsylvania for public supply purposes is surface water and less than 10 per cent is from underground sources. The cost data presented in this paper will, therefore, dwell upon the cost of developing a fully adequate and satisfactory surface supply, and will bear only slightly upon the cost of an underground source.

TABLE 2

Yield vs. Storage Required

Water Supply Yield In Gallons Per Day Per Square Mile	Storage Capacity Required in Million Gallons Per Sq. Miles
200,000 gallons	15,000,000
300,000 gallons	30,000,000
400,000 gallons	50,000,000
500,000 gallons	70,000,000
600,000 gallons	90,000,000
700,000 gallons	125,000,000
800,000 gallons	160,000,000

Surface Water Supply Sources

A surface water supply is obtained by collecting and storing the runoff resulting from rainfall. The runoff will vary greatly from State to State, and for locations within a State. Since the water used comes as rainfall, we must look into rainfall and runoff records for information to use in the design of a surface water supply.

Climatological data published by the U. S. Weather Bureau, and water supply papers published by the U. S. Geological Survey, together with information assembled by State agencies (such as the Pennsylvania Department of Forests and Waters) are most important to the design of a surface water supply. The rainfall at different points in the area under consideration is derived from standard rainfall gauges supplied with the climatological data.

Gail A. Hathaway, Assistant to the Chief of Engineers, U. S. Department of Defense,[6] has stated: "The average annual precipitation in the United States is about 30 inches, of which 70 per cent returns to the atmosphere by evaporation or by transpiration from growing vegetation. This leaves a water yield of about 8.5 inches.

"This yield is available in our streams and through wells tapping underground storage areas, but is not distributed uniformly over the United States. In fact, some of our greatest problems are due to maldistribution of water supply, both as to time and geographic areas. For example, 17 western states constitute about 60 per cent of the land area but receive only 25 per cent of the nation's water supply. The runoff for these 17 western states averages less than 4 inches. On the other hand, the runoff for 31 of our eastern states averages about 16 inches."

In Pennsylvania we are fortunate because our average rainfall is approximately 42 to 46 inches per year, and the runoff will vary between 17 and 22 inches per year. The rainfall and runoff will vary in different sections of the State, and the runoff will likewise vary with the character of the watershed. The flow in many streams run below 0.25 cu. ft. per second per square mile, while during maximum flood periods the flow in a stream might increase as much as 200 times the minimum. This condition exists in the Delaware River. The problem, therefore, is—*at times too little, and at times too much.*

The question is "How much water shall we provide in a completely adequate and satisfactory source of supply?" The answer to this question is that it should be adequate within economical limits to supply the peak demands. Generally speaking, the average rate of water consumption will be approximately as follows:

(a) The average water consumption will be approximately 100 gallons per capita per day. This includes moderate industrial usage.

(b) The consumption on a maximum day will be twice that of the average day.

(c) The maximum rate of consumption for a 3-hour period will be approximately 3.5 times the average daily rate.

(d) The maximum rate of consumption for a 1-hour period will be approximately 4-times the average daily rate.

From personal experience in a municipality with a population of over 40,000 persons, the following results were observed on July 13, 1954, during a peak day period:

(a) The average water consumption is considered as 100 per cent.

(b) The consumption on the maximum day was 157 per cent of the average.

(c) The maximum 3-hour consumption was 382 per cent of the average.

(d) The maximum hourly consumption was 520 per cent of the average.

Another example during the 1954 dry Summer period, in a municipal water plant serving some 16,000 persons, can be reported. The maximum hourly demand was at the rate of 6 million gallons per day, as compared

to an average daily demand of 1.5 million gallons per day.

These maximum daily demands do not affect a surface supply as much as they do an underground well supply and the transmission main capacity from the reservoir. The daily demands, however, do have a definite bearing upon the design of a filter plant, pumping equipment, distribution system and storage facilities.

Storage of Surface Supplies

The question may be asked as to when storage is needed on a river. It is a rare instance when storage is *not* required on an inland stream. Generally speaking, storage is required when the natural flow in a stream is less than that required for water supply purposes plus the water requirements of the downstream riparian owners.

The 1930-33 drought period should be used as the criteria. A typical example applicable to this question is the situation which occurred in Hanover, Pennsylvania, during the 1930 drought period. The daily demand upon the water works was 1.5 million gallons daily, and during the periods of maximum dryness the flow in the Creek was less than 200,000 gallons daily. This water supply agency was in serious trouble. The situation was corrected by the construction of impounding reservoir facilities.

Reservoir Depletion Curve Diagram

The so-called mass diagram or reservoir depletion curve diagram is a most useful tool for the engineer to use in determining the quantity of storage necessary to carry a water supply through an extended dry weather period. Its accuracy, of course, depends upon the accuracy of the data used in developing the mass diagram. Where actual stream flow gagings are not available, a synthetic curve can be produced from data obtainable from stream gagings on adjacent streams.

It is first necessary to determine the quantity of storage to be provided in a reservoir, and this is established from the mass diagram; and then it is necessary to prepare an area-capacity curve of the reservoir. This establishes the elevation of the water in the reservoir to provide for the storage required. The discussion of this phase of water supply problem may appear to be irrelevant to the subject at hand, but it is background material necessary to establish the basis upon which the cost estimates presented herein have been developed.

It is common knowledge that, in the period between May 1930 and July 1933, the lowest flow on record occurred. It is good practice to design a storage reservoir based on the assumption that the 1930-1933 drought will reoccur in the future. The safe yield from a reservoir to provide a fully adequate and satisfactory source of supply should, therefore, be based upon the minimum stream flows as they have occurred in the past. It is good judgment to think that the worst conditions have not as yet happened.

Design Criteria and Cost Data

Certain approximate design criteria are presented in this discussion because they have a bearing on the determination of the storage capacity which might be developed in a reservoir to produce various yields of water each day from a drainage area containing one square mile. This information is presented to assist the reader in evaluating this cost data, because, the cost of providing surface storage varies materially depending upon local physical conditions.[7] The values presented in Table 2 are approximate in nature and should be used with caution. The data will vary depending upon the size of the watershed, the stream runoff and other local factors.

Surface Water Supply Cost

A unit which might be established as a basis of presenting the cost of a surface water supply is the "cost per million gallons daily of safe yield of water." Naturally, the cost per million gallons daily varies greatly depending upon local conditions; and in order to present worthwhile data, eight actual cases will be cited, all based on the actual experience of the author.

1. Case of Chester, Pa.

As far back as 1870, the City of Chester, Pennsylvania, located along the Delaware below Philadelphia, obtained its water supply from that river. Because of the high pollution load at the water works intake, it was necessary for Chester to construct a new inland source of supply. In addition, Chester was faced with a periodic problem of combating the intrusion of salinity from the lower bay. There was sufficient volume of water in the Delaware River for Chester to obtain all of the water it needed at a low development cost, but the quality of the water was not satisfactory.

Chester moved from the Delaware River to an inland source of supply on the Octoraro Creek, 40-miles from the City. A 2.5-billion gallon capacity impounding reservoir; a filter plant and pumping station; 45 million gallons of water storage on the distribution system and 40-miles of transmission main were constructed at a cost of over $14,000,000. The population served is somewhat over 100,000 persons. The cost of purchasing the land for the impounding reservoir, road relocations, the construction of highway bridges, the clearing, grubbing and demolition, and the construction of the dam itself, including all appurtenances, was $2,900,000, excluding overhead.

The yield from this reservoir, under the drought conditions of 1930-33 is 30 million gallons per day for water supply purposes, not including the releases required by the Pennsylvania Water and Power Resources Board (amounting to 0.25 cubic feet per second per square miles of watershed area.) The drainage area is 139.6 square miles. The dam is an earth embankment dam with a combination side hill spillway and Tainter gates. The cost per million gallons daily yield from this reservoir is $96,700.00 based on 1948 construction costs. ($136,000 based on 1954 costs).

The yield from the Octoraro Creek has not been fully developed. When necessary, additional storage can be installed to increase the yield to at least 75 million gallons daily. The Chester reservoir is a fully adequate and satisfactory source of water supply, with the design taking into consideration the future growth of the area served and the additional demands of industry. When the new supply was constructed, the water demand averaged 12 million gallons daily. In 1954, the daily demands increased to almost 18 million gallons daily. At times the peak demand exceeded 20 million gallons daily.

In the case of Chester, the cost of the 40-mile pipeline and the pumping station should be considered in evaluating the total cost picture. It is pertinent to state that the cost per foot of the 48-in. pipe complete in place was $29.00; the cost of the 42-in. pipe was $26.00 and the cost of the 36-in. pipe was $21.00. The period required for the development of the Chester supply, including preliminary investigations and construction was about 5 years. Previously it had been talked about for a period of 5 years.

2. Case of Altoona, Pa.

For many years, the City of Altoona has been faced with a water shortage, and it is believed that industry has not been attracted to that

WATER STORAGE—Table Rock Reservoir, Greenville, S. C., created by an earth dam on South Saluda River

City because of this shortage. The population of Altoona has recently decreased.

A program is now under way to increase the water supply facilities. The additional supply will include an impounding reservoir with 900 million gallons total capacity, located on the 4.4-square mile Mill Run Watershed area. The estimated cost of this reservoir is $1,780,000; and the yield will be 3.5 million gallons per day based on 1930-33 drought conditions. This construction cost is $510,000 per million gallons daily of safe yield. The dam will be constructed as an earth embankment dam with a side hill spillway.

A yield of 3.5 million gallons daily from a 4.4 square mile watershed results in a yield per square mile of almost 800 thousand gallons per day. This watershed will be fully developed for water supply purposes. The high cost per million gallons daily of safe yield results from the small area of the watershed.

The unit cost at Chester of $136,000 might be compared to $510,000 per million gallons daily yield at Altoona. Attention is called to the fact that the larger watershed area and the smaller impounding reservoir result in a lower cost per million gallons per day of yield.

3. Case of Partial Yield Development

Case No. 3 involves the construction of a dam on a stream with a storage capacity of 4.4 billion gallons, and having a watershed area of 71 square miles. This dam will be a concrete structure with an overflow spillway.

The estimated cost of the dam and impounding reservoir, including road relocations, bridges, clearing, demolition, grubbing, etc., but excluding land acquisition, engineering and other overhead, is $4,140,000. The yield from the project is 16.5-million gallons per day.

The cost per million gallons daily yield is $250,000 based on present day prices. In this instance, the yield of the stream will not be fully developed. Additional storage reservoirs will increase the 71 square mile watershed yield.

4. Case of Overflow Dam

Case No. 4 involves a concrete dam with an overflow spillway. It has a capacity of 1.95 billion gallons; a surface area of 78 acres; and a drainage area of 21.4 square miles.

The estimated yield from this development is approximately 7.5-million gallons daily and the construction cost is estimated at $1,300,000. This results in a cost per million gallons daily yield of $175,000.

5. Case of Costly Road Relocations

Case No. 5 involves a water supply reservoir with a concrete dam storing approximately 2.0 billion gallons. The drainage area in this case is 21.6 square miles, and the estimated cost is $950,000. The yield is approximately 7.5 million gallons daily and the approximate cost of the development is $127,000 per million gallons daily.

This case differs from Case 4 in that expensive road relocations are required in Case 4 which are not required in Case 5. Both of these examples include land acquisition but do not include overhead. Neither of these watershed areas will be fully developed for water supply purposes.

6, 7 and 8. Cases of Large Dams

These cases involve the estimated cost of constructing three large dams on the Delaware River and its tributaries as proposed by the Incodel project. They compromise the Wallpack Bend Dam, the Cannonsville Dam, and the Fish's Eddy Dam. These cost data trended to 1954 construction costs are summarized in Table 3.

Underground Water Supply Sources

In developing completely adequate and satisfactory source of underground water supply, the criteria differ from those which are used in developing a surface supply. If water storage facilities equivalent to between 18 and 24 hours usage, under the maximum demand day conditions, are provided on the distribution sys-

TABLE 3

Summary of Cost Data for Three Large Dams

Reservoir	Est. Cost Trended to 1954	Storage Billion Gallons	Yield M.G.D.	Cost per Mil. Gals. Storage	Cost Per M.G.D.
Wallpack Bend	$ 59,028,420	91	500	$941.00	$118,000
Cannonsville	48,162,500	88.1	371	547.00	130,000
Fish's Eddy	114,712,647	117.8	479	973.00	240,000

TABLE 4

Cost and Related Data on Gravel Packed Wells

	Case 9 Morrisville, Pa.	Case 10 Rehoboth Beach, Del.	Case 11 Navy Yard, Phila.	Case 12 New Castle, Del.	Case 13 Millville, N. J.
(1) Year Drilled	1951	1951	1945	1951	1954
(2) Size of Outer Casing	24"	20"	24"	16"	18"
(3) Size of Inner Casing	10"	12"	18"	10"	12"
(4) Depth of Well	170'	125'	80'	140'	145'
(5) Yield—GPM	700	750	500	500	700
(6) Head of Pump	350'	150'	180'	140'	210'
(7) Cap. of Pump—G.P.M.	700	750	500	500	700
(8) Cost of Well	$16,000		$ 8,230	$ 5,960	$ 9,428
(9) Cost of Pump	$ 3,500		$ 2,875	$ 3,354	$ 5,741
(10) Total Cost	$19,500	$11,050	$11,105	$ 9,314	$15,169
Total Cost Price Trended to Oct., 1954	$23,600	$13,000	$23,100	$11,300	$15,200
Cost per 100 G.P.M. Yield as of Oct., 1954	$ 3,370	$ 1,740	$ 4,620	$ 2,260	$ 2,160
Cost per million gals. daily as of Oct., 1954	$23,600	$12,200	$35,300	$15,800	$15,200

tem, then a deep well supply should be capable of supplying the maximum daily demand with at least one standby well. On the other hand, if the capacity of the storage facilities on the distribution system is, for example, only 5 hours of water usage, then the deep well supply should be developed for the maximum rate of consumption for a 3 hour period, or approximately 3.5 times the average daily rate with at least one standby well.

Underground Water Supply Costs

An analysis has been made of five different well supplies, which are designated as Cases 9 to 13 inclusive. All these supplies are gravel packed type wells and are equipped with deep well turbine pumps. The cost and other data regarding these deep wells are given in Table 4.

The cost per 100 gallons per minute yield from a deep well supply, involving gravel packed wells, will vary from a minimum of $1,740.00 to a maximum of $4,620.00. This is a "bare bones" cost and does not include connecting piping, electric lines, etc.

If, however, a rock well is drilled with a probable yield of considerably less than a gravel packed well, then the cost per 100 gallons per minute yield usually will be greater than that of a gravel packed well. In certain instances, large volumes of water have been obtained from rock wells, thus resulting in low cost water.

Summary of Cost Data

The tabulation in Table 5 summarizes costs on the thirteen different water supply projects which have been discussed.

Conclusions

A completely adequate and satisfactory source of water supply should consider the future growth of a community, and water agencies will be prudent to anticipate an increased demand in the design of supply facilities. A water supply project should look forward to a growth at least 25 years in the future; where a supply can be conveniently extended, such as in the case of a deep well source, or where new surface supplies can be made available, then it is unnecessary to construct facilities for the too distant future.

It is difficult and expensive to enlarge dams and tunnels. Dams should be constructed to develop the full reservoir site capacity, when economically feasible, even though the design at the present does not require it. This does not necessarily mean that the stream or watershed area should be fully developed. This development can be done progressively in step fashion. Tunnels and long pipelines which cannot be enlarged while still being kept in service should be built to anticipate a more distant future demand than the 25-year period.

A good example of step construction on a long pipe line is that which was utilized at Chester. This 40-mile transmission main was designed for a capacity of 30 million gallons daily. The pipe was designed structurally for a pressure in excess of the pressures created when the water was flowing at the rate of 30 million gallons daily. Provision was made in the line to install, when necessary, a booster pump which would make possible an increase in the capacity of the pipe line from 30 million gallons daily to 40 million gallons daily. This same

TABLE 5

Cost Data Summary

Case No.	Type of Supply	Cost per M.G.D.
1	Surface	$136,000.00
2	Surface	$510,000.00
3	Surface	$250,000.00*
4	Surface	$175,000.00
5	Surface	$127,000.00
6	Surface	$118,000.00
7	Surface	$130,000.00
8	Surface	$240,000.00
9	Well	$ 23,600.00
10	Well	$ 12,200.00
11	Well	$ 35,300.00
12	Well	$ 15,800.00
13	Well	$ 15,200.00

* Exclusive of land acquisition.

provision was made in the pipe which conveys the water from the impounding reservoir to the filter plant. The Chester pipe line as presently constructed should be capable of serving the municipality for more than the next 25 years; and, when the booster pumps are installed, the line will then be capable of serving Chester for possibly 50 years in the future.

Since cost is a controlling element in reaching a decision in planning for the future, step construction is good practice when it is carried out in accordance with a predeveloped plan.

Finally, a good example of completely adequate and satisfactory source of water supply, constructed at a cost which the traffic will bear, is also provided by the City of Chester. The supply facilities were constructed at a cost of $136,000.00 per million gallons daily safe yield based on present day construction costs. The stream with its impounding reservoir will yield 30 million gallons daily. A reasonable future growth has been anticipated. The 1954 Summer peak demand was 20 million gallons daily. For the past 3 years, this municipality has enjoyed the benefits of a satisfactory and adequate source of water supply at a reasonable cost. The supply has successfully handled the population increase and the added industrial load.

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Water Well Operation and Maintenance

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THE value of efficient operation and maintenance of water wells is often too little appreciated. More attention is generally given to the initial installation of pumping equipment than to the construction of the well itself or to its subsequent operation and maintenance. The operation and maintenance of water wells should not be included in the problems of pumping but should be regarded as a separate problem directly related to ground water conditions and well construction.

O. E. Meinzer, formerly chief of the Ground Water Div., U.S. Geological Survey, once said that the most urgent problems in water hydrology are those relating to the rate at which rock formations will supply water to wells in specified areas, not during a day, a month, or a year, but permanently. Although this statement was made with the problems of ground water supply in mind, it also applies to the construction, operation, and maintenance of water wells.

All water wells fall into two classes: shallow and deep rock. Shallow wells obtain their water from unconsolidated formations lying above the basal rock, while deep-rock wells obtain water from the basal rock. The techniques and methods of construction differ greatly for the two types of wells. Consequently, the problems connected with well operation and maintenance are partially dependent on the type in use.

Shallow wells must depend on openings of some kind in their casings to let water into them, while deep-rock wells depend on openings in the formation for their water supply. These openings in shallow wells vary from the open bottoms of well casings to all sorts of punched, perforated, sawed, and even burned openings. Carefully designed well screens are intended to serve two purposes: to let water into the well and at the same time to keep out the finer particles of the formation in which the screen is placed. Many shallow well failures are due to poorly designed casing openings or inefficient well screens.

There are other causes for well failures, but the three most common are:

1. Failures due to the casing openings or screens becoming clogged, incrusted, or corroded. Such failures are indicated by increased drawdowns or by the continuous pumping of fine sand.

2. Failures due to pumping the ground water reservoir at rates in excess of the rate of replenishment. Such failures are indicated by a cumulative lowering of the static and pumping levels in the well, accompanied by a decrease in capacity.

3. Failures due to faulty initial well construction or to mechanical deterioration of the well during its life. Such failures are indicated by difficulty in setting and operating pumping equipment, by partial or total collapse of the well casing, or by contamination of the water being pumped.

Before anyone can properly operate or maintain a water well, he should have a working knowledge of the probable causes of well troubles and what can be done to eliminate them. Like human beings, water wells live only so long, regardless of how well they are constructed and cared for during their lifetime. Fifty years is a long life for the average water well. Shallow wells are shorter lived than deep wells, but all of them fail sooner or later.

Incrustation and Corrosion

Every operator of a water well should have some knowledge of the basic principles of incrustation and corrosion. *Corrosion* of metals is a chemical action set up by the environment to which they are exposed, resulting in the deterioration or eating away of the metal. *Incrustation,* on the other hand, is an accumulation of mineral salts or other extraneous matter in and immediately behind the openings in a well casing. These terms are frequently confused.

Corrosion of well screens is not as prevalent as incrustation, but it is more harmful, because the metal itself is destroyed. Without considerable experience and some investigation it is difficult to recognize the type of corrosion involved, as there are at least six different forms of corrosion, and the trouble may be due to any one of them.

Direct chemical corrosion is the most common form encountered in wells. It involves nothing but simple solution of the metal as a result of the chemical nature of the water. It is evidenced by a gradual enlarging of the well openings, permitting the well to pump fine sand.

Dezincification of brass and graphitization of iron are another form of corrosion frequently noted in water wells. It is the selective removal of an element from an alloy, such as the removal of zinc from brass. When this form of corrosion occurs, the metal is left in its original form but is subtsantially weakened. Examination with a microscope will reveal the extent of the structural change, but it is practically impossible to make such an examination without removing the corroded parts. This type of corrosion may be responsible for sudden failures of well casings or screens and of pumping equipment that appears to be sound.

Intergranular corrosion is a localized chemical reaction at the boundaries of metallic crystals. It is an amalgamating action and very destructive. Fortunately, it is not often encountered in wells. Little can be done to guard against it, except to avoid the use of amalgamating agents.

Galvanic or bimetallic corrosion is a localized attack which often results when two dissimilar metals are connected in an electrolyte. Under such conditions, a simple electric cell is created, with the anode being corroded. Almost the only thing that can be done to eliminate or retard this form of corrosion is to place lead plates in the well in such a position that they intercept and absorb the low-potential currents. The safest protection is to use the same metal throughout the entire well, including the pumping equipment.

Concentration cell corrosion is occasionally encountered in wells, although it is rare and extremely difficult to recognize without the aid of expert chemists and physicists. It is the form of electric cell set up when one metal is placed in two different concentrations of the same electrolyte. This type of difficulty is evidenced by local corrosion occurring at random on the corroded surface.

Most *ground waters* found in sands, gravels, and similar formations are only mildly corrosive, if at all. Generally, a mineral analysis of the water will indicate the proper metal to use in the well installation. Dissolved oxygen is probably the most important constituent in determining

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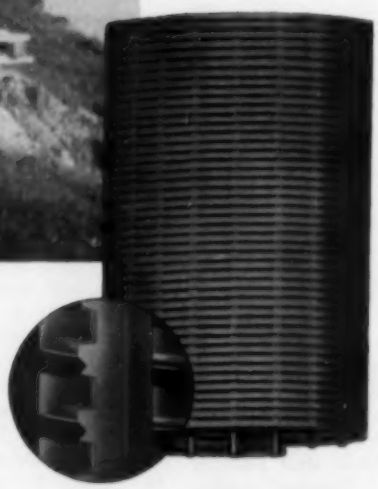

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the likelihood of ground water corrosiveness. Hydrogen sulfide is another agent which is a sure sign of corrosiveness. The balance between dissolved carbon dioxide and the carbonates of magnesium and calcium, in combination with dissolved oxygen, determines the degree of corrosiveness of most ground water, as well as the probability of incrustation. Water with a low pH (high acidity), low carbonate hardness, and high carbon dioxide content is almost certain to be corrosive. Water with a high pH and low proportion of carbon dioxide will not usually attack the metals used in wells or pumps.

The rate of corrosion is dependent on a number of factors, one of them being the rate of movement of water over the surface being corroded. To offset corrosion in wells and pumps, two general methods of approach are common: one is the use of protective coatings, and the other, the use of highly corrosion-resistant metals. Neither method has proved to be a wholly effective safeguard against corrosion.

Incrustation of well casings, openings, and screens is a deposition of materials in and around all metal parts of wells and pumps. These accumulations are made up largely of the bicarbonates and sulfates of calcium, magnesium, sodium, and iron. Hydroxides and oxides of iron with other substances such as chlorides, borates, and silicates may be present but only add to the amount and kind of deposits formed. Iron and manganese compounds are the most difficult to break down and remove, as they form a relatively hard deposit. Silt and clay may be in suspension in the water and contribute their bit to the accumulations of incrustation. Other agents contributing to incrustation are the iron bacteria and slime-forming organisms such as *Crenothrix*.

No way has yet been found to prevent or entirely remove these accumulations in and around well screens and pumps. All that can be done is to take steps to retard such action. One measure is to provide the maximum amount of transmitting capacity in the casing or screen openings either by rebuilding the well or by replacing it with a new one of better design. Another step is to lower the rate of pumping and increase the period of pumping. This will be effective if drawdown is materially reduced. Many well owners are finding it more economical to operate a large number of properly spaced wells, with less drawdown, than to try to obtain their requirements from a few wells having excessive drawdowns.

Wherever incrustation is present, as shown by past experience, periodic cleaning of wells and pumps should be made a regular item of maintenance. Such corrective measures should be initiated at the first suspicion of incrustation. Otherwise, costly rehabilitation may be necessary, with questionable results.

Acid treatment is by far the most common means of removing incrustation. Hydrochloric acid used with an inhibitor readily dissolves the carbonates of magnesium and calcium, as well as the hydroxides and oxides of iron and manganese. Chlorine in both liquid and gaseous form has been used with some success, especially in removing the accumulations of slime-forming organisms. This method does not, however, prevent recurrence of the trouble.

Other chemicals, such as sulfuric acid, sodium hexametaphosphate, copper sulfate, and carbon dioxide (in the form of dry ice), have been tried in many places as a means of removing incrustation, with mixed results. As yet there is no established technique for treating wells with chemicals or removing accumulations by the use of scrapers, brushes, compressed air, water, or steam. Each job of this kind must be carefully studied, taking into account the chemistry involved—as the amount of incrustation depends primarily on the minerals carried by the ground water—and also the rate of pumpage.

Well failures due to a low rate of ground water replenishment can be corrected only by regulating the pumping rate to conform with the replenishment rate. There is no other answer. Many have tried to maintain well supplies by installing larger wells and pumps, but the safe annual yield of a well is definitely limited to the amount of annual water replenishment of the underground reservoir.

Well failures due to poor construction, or to mechanical troubles after construction, are in the minority. Such failures are caused mostly by the use of cheap materials, poor construction methods, improperly designed screens, poor gravel treatments, and the like. These failures usually give little or no warning. A well may suddenly collapse or start pumping large quantities of formation material. Such failures can, of course, be avoided by proper design and construction. Once the well is in operation, however, little can be done to prevent failures of this type.

Deep-Rock Wells

The nature, construction, and hydraulic characteristics of deep-rock wells are so different from those of shallow wells that they require special consideration and careful supervision at all times. The maintenance and operation of deep-rock wells is largely a question of good judgment, coupled with experience. The water supply of deep wells depends upon the kind of rock in which they are drilled, its ability to transmit water, the nature of the water itself, and its source of origin. All deep-rock wells, with the exception of wells in sandstone, get their water from rock fractures or from solution channels. The water table in rock wells slopes from the surface intake to the well, usually at a much flatter slope than the water table in an unconsolidated formation. Hence, the water moves under different hydraulic conditions and invariably is in a confined rather than a free state. This means that the supply of a deep-rock well is obtained from water rising through the larger fractures to the point of discharge. Because the water level in a deep-rock well controls the water level in the formation, the yield from deep-rock wells may vary widely even though they are located in the same rock formation. On account of the presence or absence of rock fractures, one well may be much better than another even though the two are not far apart. If the fractures in the rock at the well are enlarged or increased by shooting, but the use of acids, or by mechanical means, the water level in the formation may be raised or lowered, thus decreasing or increasing the capacity of the well.

Consequently, the use of explosives in a deep-rock well is not always good practice. Shooting a deep-rock well frequently does more harm than good, as the well may be filled with rock debris or new fractures which are filled with fine material may be opened. The job of cleaning rock wells that have been shot is just as important as the shooting itself. The shooting of wells should always be carried out by persons thoroughly experienced in this kind of work, under the supervision of someone who knows the geology of the formation.

Mechanically there is very little that can be done to maintain a deep-rock well supply. Most operators find it necessary to go into such wells occasionally for the purpose of keeping the fractures or solution channels open. The sides of the drill hole can be scraped or brushed to remove any accumulations present. If the drill hole has become partially filled with rock debris, it is cleaned out by bailing. Chemical treatment and surging are helpful in dissolving certain kinds of accumulations in the fractures.

Wells constructed in limestone, dolomite, gypsum, and similar formations often obtain their water from solution channels rather than rock fractures. Solution channels are created by the solvent action of water entering the vertical joints of the formation at the surface and then finding its way to the horizontal joints, which are fractures. The dissolving effect of water in such formations is well known. It is particularly effective above the water table where the movement is comparatively rapid and the water contains the maximum amount of carbon dioxide. It must be remembered, however, that the fractures and channels below the water table act as a network of reservoirs supplying deep-rock wells. Obviously, there may be considerable variation in the supply from the same type of formation in different localities, owing to the presence or lack of caverns and major channels. In some places, a well will pass through limestone without striking a water-bearing channel or fracture at all.

The chemical constituents of water obtained from deep-rock wells depend largely on the chemical nature of the rock itself, the rate of flow, and the temperature. As a rule, water from deep-rock wells is warmer and more highly mineralized than water from shallow wells. Although better protected against pollution, it is not at all uncommon for deep-rock wells to become polluted. The origin of such pollution is difficult to locate and trace. It may be due to carelessness in and around the well, to surface contamination originating at a considerable distance from the well, or to improper installation and operation of pumping equipment.

On account of the cost and nature of deep-rock wells, they are generally pumped at greater drawdowns than shallow wells. Air lift pumping will sometimes maintain a supply when the conditions in the well are such that other types of equipment cannot be used. One of the chief causes of failure in deep-rock wells is the lowering of the water table or pressure level to a point at which it is no longer economical to pump the well. This again emphasizes a fundamental of good well operation—the regulation of pumping rates to the amount that can be safely withdrawn annually.

Protective Measures

In operating wells, there are a number of things that can be done to maintain and protect a ground water supply. The following suggestions are offered:

1. All wells should be located and constructed by men who are experienced in this sort of work and who have some knowledge of the occurrence and movement of ground water in various water-bearing formations.

2. All wells should be located so that they will not interfere with other wells operating in the vicinity.

3. All wells should be constructed in such a way that only water which is free of pollution and is of usable quality can get into them.

4. All wells and pumping equipment should be constructed of materials that will resist the corrosive and erosive action of the water being pumped, as well as the action of chemicals which may be used to remove accumulations.

5. All wells should be operated at their most economical point by equipping them with pumps properly designed for the characteristics of each installation. This means that well operators should have a method of measuring the yield, drawdown, and power consumption of every pumping unit under their care.

Conclusion

Good operation and maintenance of a well supply are primarily the well owner's responsibility. He must provide the best well construction, pumping equipment, and supervision that he can obtain. The operation and maintenance of a well water supply are a great responsibility, but municipalities, industries, and private owners often take it too lightly. They are not concerned until something unfortunate happens, but when a water supply fails, there are plenty of questions asked, with the blame usually falling upon the party least responsible.

The author does not mean to imply that the operator of a water well has no responsibility, for he has. His responsibility is to inform himself regarding the wells under his care. He must know enough about the methods and materials used in constructing wells to be able to anticipate any trouble from these sources. Furthermore, he should know enough about the local water-bearing formations and the water in them to be able to advise the owner of any overpumping or reduction in supply.

The operator should insist on having the apparatus and assistance required to make periodic readings of water levels, pumping levels, quantity of water pumped, and power consumption. It is essential to make these data a matter of record, because they will be invaluable in any emergency which might arise. Such information will also be helpful in anticipating shortages due to increased demands or failure of wells and pumping equipment.

In Illinois, a recent survey disclosed the fact that, out of 23 municipal supplies from shallow wells, only one metered the pumpage. None reported making measurements of water levels, either static or pumping. The survey also disclosed that, in a group of thirteen deep-rock wells, none metered the pumpage or made any systematic effort to determine the performance of the wells. This record probably could be duplicated in any section of the country. This sad state of affairs cannot be charged entirely to the operators of well supplies, as they are often burdened with other duties, varying from dogcatcher to night watchman. It goes without saying that inefficient operation adds to operating costs. For this reason alone, operators of well supplies should be allowed to devote their entire time and ability to bettering the operating conditions of their well installations. Most operators are capable of doing their job if given the chance.

DISTRIBUTION

THE ELEMENTS of a complete distribution system include distributing reservoirs, conduits or transmission mains, and pipe lines. Accessories to a distribution system include booster stations, valves, hydrants, main line meters, and service connections.

The importance of distribution systems is indicated by these facts: Pipe lines in water works handle a greater tonnage per day than any other transportation system; approximately 66 per cent of the total value of water works is in the distribution system; approximately 80 per cent of the distribution system value is in mains and valves.

Distributing Reservoirs

The functions of distributing reservoirs are to: Equalize hourly or daily flow; provide and maintain desired pressure in remote areas; and to provide emergency storage for fire protection purposes. Distributing reservoirs also permit equalization of pumping heads, economies of construction, economies of operation, and reduction of pressure fluctuations.

Distributing reservoirs may be of steel, reinforced concrete, earth or wood and may be located at or below ground level (ground storage) or above ground level (elevated storage). Elevated storage may be in tanks or standpipes.

Distributing reservoirs are located at a point near the center of consumption, near areas where improved pressure is needed, on high ground, and on a site that gives greatest advantages for lowest construction costs.

The capacity of distributing reservoirs depends on maximum rate of consumption, maximum pumping capacity, minimum safe yield of source of supply, and fire flow requirements. Reserve storage for fire protection emergency must be provided if pumping capacity is not sufficient to meet requirements for fire flow set by Nat. Bd. Fire Underwriters. Reservoirs float on the system. When pumps operate at average rate, storage tanks fill or empty depending on whether or not the rate of consumption is above or below the pumping rate.

Conduits and Transmission Mains

Water from a supply source or pumping station travels to a distribution net work by gravity in conduits or open channels or in pressure lines termed transmission mains.

Gravity conduits may be canals, flumes, or aqueducts. Pressure lines may be cast iron, steel, reinforced concrete, or wood stave. Transmission lines are located to take the shortest route possible. Pressure lines should avoid peaks and depressions. The size should be based on estimated capacity 25 years in the future. Twin lines are frequently used as a protection in case of failure and to allow cleaning.

Pipe Line Materials

Materials used in distribution systems include cast iron in all sizes, reinforced prestressed concrete (generally in larger sizes) asbestos-cement (generally below 24 in.), steel (generally larger than 36 in.) and wood stave (mainly for irrigation, and industrial supplies).

As a protection against corrosion, metal pipes are lined, either with a coal-tar-pitch varnish (bituminous tar) or cement lining added during manufacture or in place.

Joints for pipe depend on the type of pipe. Cast iron pipe may be bell and spigot, flanged, universal, mechanical, or flexible ball joints. Concrete uses a rubber ring and offset joint forced together under tension. Asbestos-cement pipe uses a rubber ring on a tapered end with the joint covered by a sleeve which holds the rubber ring under compression. Bell and spigot joints are sealed with lead or sulfur joint compounds poured hot against a packing ring of jute, braided paper or rubber.

Fittings include curves or ells (22½, 45, and 90 deg.); reducers, tees, wyes, crosses, and sleeves.

Network Systems

The distribution system consists of three parts: Supply mains, (also termed transmission mains) carry water from source or pump station to sections of a city. Arterial mains are secondary feeders connected to supply mains. Minor distributors make up the gridiron between the arterial mains and supply both domestic consumers and fire hydrants. The location and sizing of mains depend on the area to be served, the number of customers, the required fire flow for the area, number of fire hydrants.

Booster stations consist of pumps which take water from a supply main and discharge it at a higher pressure at another point in the line. Booster stations increase line pressure in outlying areas when head loss is too great in the line. They may be operated in connection with elevated storage tanks and are controlled either by pressure or by a combination of flow and pressure (Pressureflo).

Valves and Hydrants

Valves are located on all branches from feeder mains and between minor distributors and hydrants. They should be placed at least every 1200 ft. on arterial mains and minor distributors and at lesser distances in high value areas.

The types of valves used on distribution lines include butterfly valves, cone valves and gate valves. Check valves are automatic valves that allow water to flow in one direction only. Back flow preventers are special types of check valves used in cross connections between domestic and industrial supplies. Altitude valves in elevated storage tanks to control flow into or out of tank depending on line pressure and water level in the tank.

Hydrants for fire protection service are located according to area to be served, population, district value, length of fire hose that can be served, and method of obtaining required fire pressure. Types of hydrant most commonly used has two 2½-in. hose outlets and one 4-in. pumper outlet. They are located from 2 to 6 ft. from the curb.

Meters and Services

Main line meters (Venturi tubes, Dall Flow Tubes, propeller meters) are used to determine flow of water entering the distribution system or at points of interconnections. They should have high accuracy and low head loss.

Services are small pipes which connect the street mains to the consumer's house. They are usually ¾ to 1½-in. in diameter and may be of galvanized iron, copper, lead, or plastic. Service meters are the cash register of a water works; they may be owned by the utility or by the consumer; they should be checked at regular intervals of 5 to 7 years, oftener if readings appear unusual.

Operators of a distribution system meet many problems such as fire rating, fire flow, pressure, main sizing, main laying, tapping, hydrant and valve maintenance, leak surveys, etc.

CHICAGO BRIDGE & IRON COMPANY

Since 1893, Chicago Bridge & Iron Company has been designing, fabricating and erecting elevated steel tanks and many other types of steel plate work for municipal water systems throughout the country. These 62 years have been years of progress. They have given us a vast background of experience which has led to structural improvements, better workmanship and efficient erection methods. Tank designs have been constantly improved to provide today's pleasing, streamlined structures.

Tanks for municipal service are built by Chicago Bridge & Iron Company in accordance with specifications of the American Water Works Association. Four strategically located plants in Birmingham, Chicago, Salt Lake City and Greenville, Pennsylvania are always ready to serve you.

ELEVATED WATER TANKS

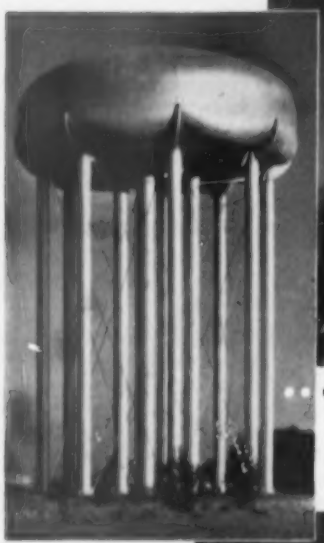
Horton elevated water tanks are designed to provide dependable gravity pressure in water distribution systems. They usually reduce pressure variations in the mains and often cut down pumping costs.

Horton elevated water tanks are built in five basic types—ellipsoidal-bottom tanks, radial-cone bottom tanks, Waterspheres, Waterspheroids and Hortonspheroidal tanks. We shall be pleased to submit estimating figures or quotations on any of them. When writing please state capacity, height to bottom, range in head, location and shape or design desired. There is no obligation on your part.

WATERSPHERES

The smooth, streamlined Watersphere presents a pleasing appearance. All piping connections and ladders are located inside the supporting column to which access is provided by a door at ground level. The lower portion of the supporting column may also be used as a pumphouse.

Capacity in Gallons	Diameter of Sphere
25,000	19'4"
30,000	20'4"
40,000	22'4"
50,000	24'0"
60,000	25'6"
75,000	27'4"
100,000	30'0"
150,000	34'0"
200,000	37'6"
250,000	40'6"



ELLIPSOIDAL-BOTTOM WATER TANKS

Ellipsoidal-bottom elevated tanks are relatively large diameter and shallow depth. Unless otherwise specified, they are built with cylindrical columns and ellipsoidal roofs.

Gallons Capacity	Tank Dimensions	
	Diameter	Range
50,000	22'0"	19'0"
60,000	24'0"	19'0"
75,000	26'0"	21'0"
100,000	28'0"	24'0"
125,000	30'0"	25'6"
150,000	32'0"	27'6"
200,000	36'0"	29'6"
250,000	40'0"	29'0"
300,000	43'0"	30'0"
400,000	46'0"	35'0"
500,000	50'0"	37'6"

HORTONSPHEROIDAL WATER TANKS

Hortonspheroidal elevated tanks are modern, attractive structures. They are built in standard capacities of 1,000,000 to 3,000,000 gallons and are supported either on two rings of cylindrical columns or one ring of cylindrical columns and a large central riser.

Gallons Capacity	Tank Dimensions	
	Diameter	Range
1,000,000	87'6"	25'
1,000,000	81'0"	30'
1,500,000	92'0"	35'
2,000,000	106'0"	38'
2,500,000	117'0"	35'
3,000,000	120'0"	40'

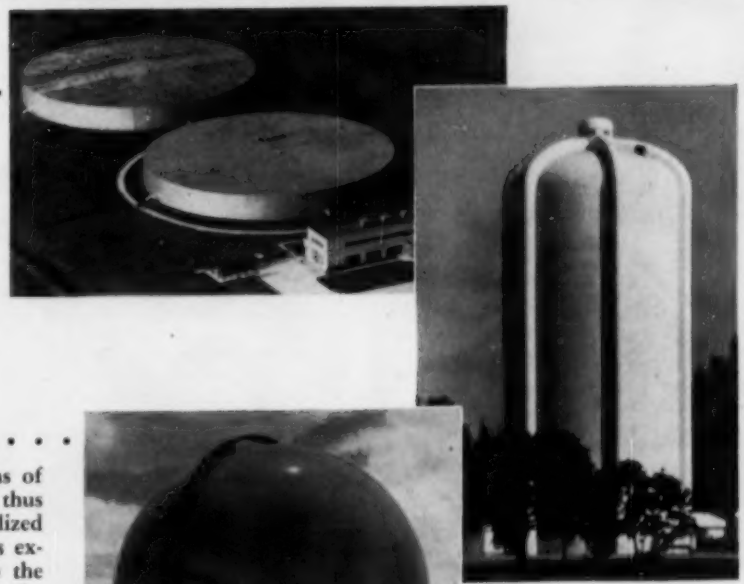
RADIAL-CONE BOTTOM WATER TANKS

A functional design that permits large capacity water tanks to be built with a relatively low range in head. They are pleasing in appearance and easy to maintain.

Gallons Capacity	Tank Dimensions	
	Diameter	Range
500,000	60'4"	25'
750,000	74'3"	25'
750,000	67'6"	30'
1,000,000	86'0"	25'
1,000,000	78'0"	30'
1,000,000	71'6"	35'
1,500,000	104'0"	25'
1,500,000	96'0"	30'
1,500,000	88'0"	35'
2,000,000	112'0"	30'
2,000,000	102'0"	35'
2,500,000	114'0"	35'
3,000,000	117'0"	40'

CHICAGO BRIDGE & IRON COMPANY

WELDED STEEL RESERVOIRS . . . . . .



Chicago Bridge & Iron Company builds welded steel reservoirs and standpipes in standard capacities up to 10,000,000 gals. Also in special designs similar to those shown in the views at the right. Our careful fabrication and erection methods assure a long service life. Welded construction resulting in smooth tank surfaces makes painting and maintenance easy and less costly.

HORTONSPHERES FOR DIGESTER GAS . . . . . .

Hortonspheres provide an economical means of storing sewage plant gas under pressure, and thus permit the gas produced in digesters to be utilized effectively. When the *supply* of digester gas exceeds demand, the surplus is pumped into the Hortonsphere. When the *demand* exceeds the supply, gas flows from the Hortonsphere to make up the difference. The entire shell of the Hortonsphere is accessible for inspection and painting. Hortonspheres are built in capacities up to 1,500,000 cu. ft.

PHOSPHORIC ACID PROCESS PICKLING AND PAINTING

The Horton phosphoric acid process saves maintenance dollars and prolongs the life of steel plate structures. It removes mill scale before shipment from our plants and helps provide a better bond between the prime coat of paint and the steel.

STEEL PLATE WORK . . . . . .

Our design, fabrication and erection departments have had years of experience in supplying water and sewage plants throughout the country with all types of heavy steel plate work. When requesting quotations on steel plate work we would appreciate receiving plans and specifications.

CONKEY SLUDGE FILTERS . . . . . .

Over 2,000 tons of various sludges and industrial wastes (primary—elutriated digested—bio-chemical —industrial) are daily dewatered on Conkey Sludge Filters. Every municipal and consulting engineer should be acquainted with the advantages and trouble-free performance of Conkey equipment, fabricated by CB&I.

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Storage on the Distribution System

by CHARLES B. BURDICK
Cons. Engr., Alvord, Burdick & Howson, Chicago, Ill.

IT HAS been aptly said that elevated storage is like money in the bank. It represents work already accomplished and an asset that can be drawn upon for instant use when needed.

Unlike storage on any other part of the water works system, storage on the distribution system is actually beneficial to every part of the water works, extending all the way back to the source of supply, through feeder pipes, pumps, treatment facilities and, in many cases, the water development facilities.

Like money in the bank, wherein only a certain amount is necessary for day to day commercial transactions, enough is enough. Money invested in excessive storage would better be devoted to something more needed. It is the present purpose to show how much storage may be warranted under general conditions and the available means for accomplishing it, bearing in mind that no two cases are exactly alike and that while the conditions surrounding most water works are similar, there are wide variations in conditions affecting certain cases. Therefore each case should have separate study if the project is to be both technically and economically sound.

A basic discussion of this important topic prepared especially for the Reference and Data Number of *Water & Sewage Works* at our request.—The Editors.

Generally speaking, that water works system is the best that provides facilities adequate to meet all conditions of service, including rare emergencies, at the least cost. The latter takes into consideration expenses of operation balanced against capital costs, usually represented by interest and depreciation upon the investment.

Storage upon the distribution system is of principal value in the form of adequacy and reliability of service, and in its economy. It is justified to the extent that it increases more constancy of pressures and greater reliability and economy, bearing in mind that in practically all installations allowance must be made for the probable service requirements for a reasonable period in the future. Both reliability and economy are promoted by the effects of storage in securing more economical pumpage, and in providing an assured pressure and adequate volume of water for fire protection.

Conditions Affecting Storage

Every water works man would have his problem much simplified, and the investment in water works would be much reduced, if water could be served at a uniform rate of delivery throughout the year. This is impossible, however. The consumer properly demands water when he needs it, and needs vary widely with the seasonal extremes and wide variations in demand throughout the hours of the day.

Storage is particularly beneficial in the afternoon or evening hours upon a few days in exceptionally hot and dry summers. Such summers do not come every year, and therefore excessive demand often comes as a surprise. An examination of many pumping records indicates that the demands of one summer in five or ten may greatly exceed the ordinary summer. Therefore, in providing facilities for storage it

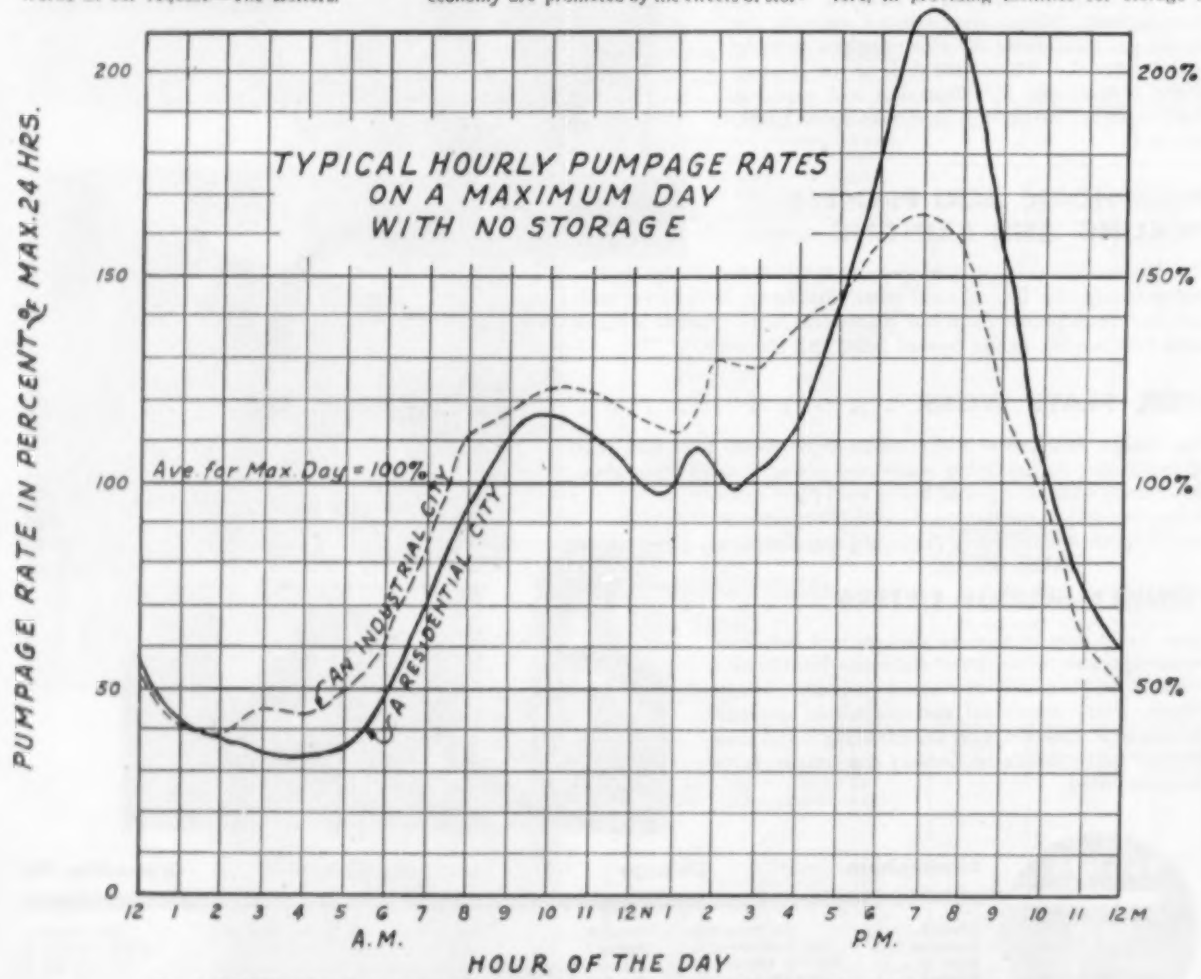


Fig. 1. RANGE of hourly pumpage rates on maximum days—typical of cities without distribution storage.
(Pattern for residential city compared with industrial city.)

is wise to allow a liberal percentage above average requirements in providing storage facilities.

The accompanying Table I is an analysis of the service requirements on five water works systems in cities varying from 37,000 to 320,000 population during years that are known to represent a well defined maximum in each city.

In these statistics the hourly pumpage rates were studied and correction was made for a small amount of elevated storage in several cases so that the figures would represent pumpage necessary to supply demand without storage. Fig. 1 shows diagrammatically the hourly rates of pumpage upon a maximum day for two cities, which represent common maximum and minimum conditions as to pumpage variation. There are some very large cities where use is more uniform. For more ready comparison, the pumpage rates have been expressed in percentage of the average pumpage rate (total pumpage) during the 24 hours of a maximum day. With information similar to this for any city, it is possible to compute the amount of storage which if most effectively liberated would make it possible to operate the pumps at a uniform rate throughout the 24 hours of a maximum day. In other instances, notably the small municipality, adequate storage can sometimes make possible the complete pumping requirement during the period of money-saving off-peak power rates.

Hourly variations in pumpage depend upon the character of the city in regard to similarity of use. Perhaps the most important consideration is the extent of industrial use. This can be and usually is a more or less uniform use. Upon the other hand, residential consumers use little or no water at night and make heavy demands at certain hours of the day, particularly during the early evening hours; and to this is added a very exceptional demand for lawn sprinkling on hot summer days. Recently, water used in cooling systems has placed an added burden on hot weather peak hours. In most cities the varying residential demand is more or less ironed out by commercial and industrial uses, and the extent of commercial and industrial use is probably largely accountable for differences in pumpage rates when comparing cities.

TABLE 1
Variations in Pumpage in Five Cities

Character of City	1 Residential	2 Industrial	3 Residential	4 Residential	5 Industrial
Population	37,366	100,426	110,468	307,000	320,000
Ave. pumpage MGD	3.69	9.61	6.94	17.50	43.80
Gals. per capita	99	96	63	57	137
Max. 24 hrs. MGD	5.09	17.42	13.66	30.65	70.20
Gals. per capita	136	174	124	100	220
Per cent of ave. day	138%	182%	196%	175%	160%
Max. hr. MGD	8.05	35.80	30.36	53.00	115.70
Gals. per capita	216	358	278	174	360
Per cent of max. 24 hrs.	158%	205%	222%	172%	165%
Storage to Equalize Hour Peaks					
In gals. per capita	24	33	31	14	50
In % of max. 24 hrs.	18%	19%	25%	14%	23%
Reduced Pumpage Peak by Storage in—					
Gals. per capita	80	184	154	73	140
Per cent of max. 24 hrs.	37%	51%	55%	42%	39%

How Storage Improves Pressure

Fig. 2 is a cross section showing ground occupied by a city, and certain lines illustrating available water pressure created by a pumping station.

The line AB illustrates the drop in pressure in a case where no elevated storage exists, and pump pressure is so used up in deficient pipes that no pressure remains at the peak hour of the heaviest pumpage (demand) day at the remote end of the town.

With an elevated tank installed the pressure conditions are changed as follows upon a similar heavy pumpage day. Assume the storage is such that the pumps instead of running at a variable rate run a constant rate day and night. During the peak hour of use pressure will be represented by the line AC representing water flowing from the pumps. The line DC represents water flowing from the tank toward the pumping station, and line DE.

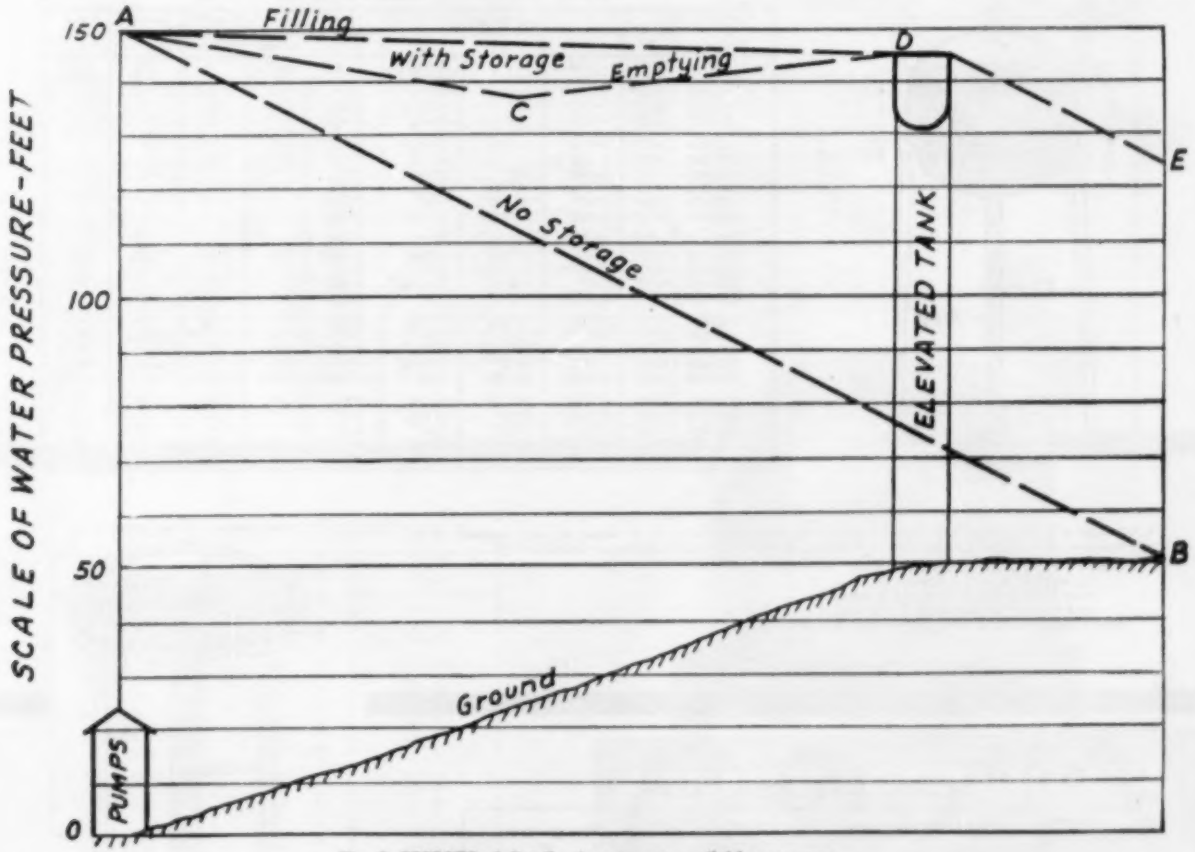


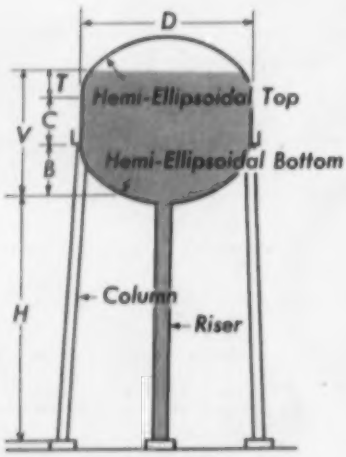
Fig. 2. EFFECTS of distribution storage available pressures
(Shown for a maximum demand day.)

Capacities and Sizes of

STANDARD ELEVATED STEEL TANKS

by PITTSBURGH · DES MOINES

In these compact but complete tables, data are furnished on the various types of elevated steel tanks, and on steel reservoirs. For full information as to the application of these tanks, for designs, for specifications, or for estimates, write—without obligation to our nearest office.



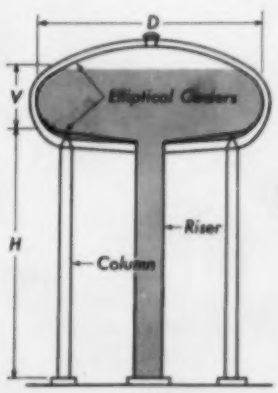
Double Ellipsoidal

TABLE I—DOUBLE ELLIPSOIDAL TANKS

Capacity U.S. Gallons	Tank Dimensions D	V	B	C	T	Balcony Width	Number of Columns	Radial Bevel of Columns	Tower Height H
25,000	18'0"	14'4⅜"	4'9"	6'0⅛"	3'7½"	24"	4	1:12	see note**
30,000	18'0"	17'0"	4'9"	8'7⅜"	3'7¼"	"	"	"	"
40,000	20'0"	18'6½"	5'2⅜"	9'4¼"	4'0"	"	"	"	"
50,000	22'0"	19'2½"	5'11"	8'10¾"	4'4⅜"	"	"	"	"
50,000	24'0"	16'8⅛"	6'4⅛"	5'6⅜"	4'9⅛"	"	"	"	"
60,000	24'0"	19'7½"	6'4⅛"	8'5⅜"	4'9⅛"	"	"	"	"
75,000	26'0"	21'2⅛"	6'10½"	9'1¼"	5'2⅜"	"	"	"	"
100,000	28'0"	23'8⅜"	8'7"	9'6½"	5'7¼"	"	"	"	"
100,000	30'0"	21'0⅜"	8'11"	6'1⅜"	6'0"	"	"	"	"
150,000	32'0"	27'4"	9'4⅛"	11'7"	6'4⅜"	"	"	"	"
150,000	34'0"	24'9⅜"	9'10½"	8'1⅜"	6'9⅛"	"	"	"	"
200,000	36'0"	29'4½"	10'6⅛"	11'8"	7'2⅜"	"	"	"	"
250,000	38'0"	33'0"	11'3⅜"	14'3⅜"	7'4⅛"	30"	6	1:20	"
250,000	40'0"	30'10½"	11'10½"	8'6"	10'6"	"	"	"	"
300,000	44'0"	30'9"	13'0½"	7'11⅜"	9'8⅛"	"	"	"	"
400,000	48'0"	34'3⅛"	14'7"	11'0"	8'8⅛"	"	"	"	"
500,000	50'0"	39'0⅜"	15'6⅛"	15'5⅛"	8'0⅛"	"	8	"	"
500,000	55'0"	29'11"	12'0"	10'11"	7'0"	"	"	Vertical*	"
600,000	50'0"	43'10½"	15'6⅛"	22'3¼"	8'0⅛"	"	"	1:20	"
750,000	60'0"	41'7⅛"	18'0"	11'10⅜"	11'9"	"	"	Vertical*	"
750,000	65'0"	37'0⅛"	20'1⅜"	6'5"	10'5½"	"	"	"	"
1,000,000	65'0"	47'1⅛"	20'1⅜"	16'5⅜"	10'5½"	"	10	"	"
1,000,000	70'0"	42'6½"	23'0"	10'9½"	8'9"	"	"	"	"
1,000,000	75'0"	35'0"	20'6"	8'o"	6'0"	"	"	"	"
1,250,000	70'0"	51'2⅜"	23'0"	19'5⅜"	8'9"	"	12	"	"
1,500,000	70'0"	59'10⅛"	23'0"	28'1⅜"	8'9"	"	"	"	"

* Standard practice is to make columns vertical for Double Ellipsoidal Tanks whose diameter exceeds 50 ft. However, their columns may be inclined if desired, in which case their radial bevel would be 1:20.

** Standard tower heights (H) are as follows:
Up to 50 ft. in even 2 ft. intervals,
from 50 ft. to 100 ft. in even 5 ft. intervals,
and over 100 ft. in even 10 ft. intervals.
Most common standard tower heights are 75 ft. and 100 ft.



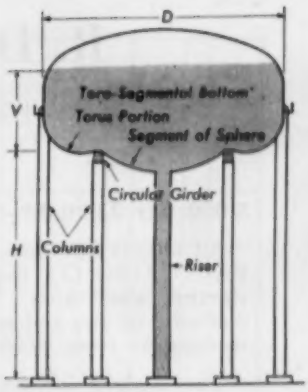
Obloidal

TABLE II—OBLOIDAL TANKS

CAPACITY U.S. GALLONS	DIAMETER D	HEAD RANGE V	TOWER HEIGHT H
1,000,000	88' 0"	25' 0"	As Required
1,500,000	92' 0"	35' 0"	" "
2,000,000	106' 0"	35' 0"	" "

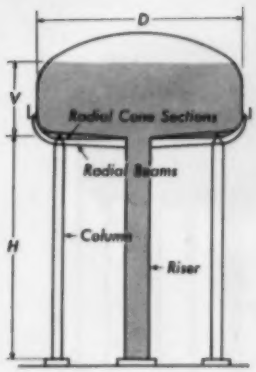
TABLE III—TORO-SEGMENTAL BOTTOM TANKS

CAPACITY U.S. GALLONS	STANDARD HEAD RANGES V			TOWER HEIGHT H
750,000	25′ 0″			As Required
1,000,000	25′ 0″	30′ 0″	35′ 0″	" "
1,500,000	25′ 0″	30′ 0″	35′ 0″	" "
2,000,000		30′ 0″	35′ 0″	" "
2,500,000		30′ 0″	35′ 0″	" "
3,000,000		30′ 0″	35′ 0″	" "



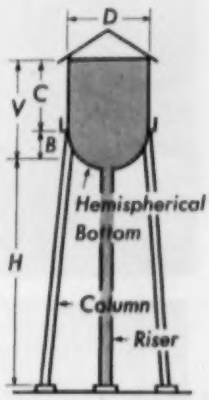
Toro-Segmental

TABLE IV—RADIAL CONE BOTTOM TANKS



Radial Cone

CAPACITY U.S. GALLONS	TANK DIMENSIONS D	V	NUMBER OF COLUMNS	TOWER HEIGHT H
300,000	53′ 0″	20′ 0″	8	As Required
500,000	60′ 0″	25′ 0″	"	" "
750,000	73′ 0″	25′ 0″	"	" "
750,000	67′ 0″	30′ 0″	"	" "
1,000,000	85′ 0″	25′ 0″	10	" "
1,000,000	77′ 0″	30′ 0″	"	" "
1,000,000	71′ 0″	35′ 0″	"	" "
1,250,000	95′ 0″	25′ 0″	12	" "
1,250,000	87′ 0″	30′ 0″	"	" "
1,250,000	80′ 0″	35′ 0″	"	" "
1,250,000	74′ 0″	40′ 0″	"	" "
1,500,000	103′ 6″	25′ 0″	"	" "
1,500,000	95′ 0″	30′ 0″	"	" "
1,500,000	88′ 0″	35′ 0″	"	" "
1,500,000	81′ 6″	40′ 0″	"	" "
2,000,000	108′ 6″	30′ 0″	16	" "
2,000,000	101′ 0″	35′ 0″	"	" "
2,000,000	94′ 0″	40′ 0″	"	" "
2,500,000	121′ 6″	30′ 0″	"	" "
2,500,000	112′ 0″	35′ 0″	"	" "
2,500,000	105′ 0″	40′ 0″	"	" "
3,000,000	123′ 6″	35′ 0″	20	" "



Hemispherical Bottom

TABLE V—HEMISPHERICAL BOTTOM TANKS

Capacity in U.S. Gallons	Tank Dimensions D	V	B	C*	No.** of Columns	Balcony Width	Tower height from foundation top level to bottom capacity level of tank (H)††						
5,000	9′0″	11′ 0⅜″	1′2½″†	9′ 9⅜″	4	None	31′ 9″	38′3″	51′9″	58′9″	72′9″	79′9″	93′ 9″	100′ 9″
10,000	13′0″	11′ 7⅛″	6′0″	5′ 7⅛″	4	None	30′ 0″	40′0″	50′0″	60′0″	70′0″	80′0″	90′ 0″	100′ 0″
15,000	13′0″	16′10⅛″	6′0″	10′10⅛″	4	None	30′ 0″	40′0″	50′0″	60′0″	70′0″	80′0″	90′ 0″	100′ 0″
20,000	13′0″	21′ 8″	6′0″	15′ 8″	4	None	30′ 0″	40′0″	50′0″	60′0″	70′0″	80′0″	90′ 0″	100′ 0″
25,000	15′0″	19′10½″	5′4″	14′ 6½″	4	18″	44′ 8″	50′0″	69′8″	75′0″	94′8″	100′0″	125′ 0″	
30,000	15′0″	23′ 8¼″	5′4″	18′ 4¼″	4	18″	44′ 8″	50′0″	69′8″	75′0″	94′8″	100′0″	125′ 0″	
40,000	17′0″	24′11¼″	6′8″	18′ 3¼″	4	24″	46′ 3″			75′0″	96′3″	100′0″	125′ 0″	
50,000	19′0″	25′ 6″	8′0″	17′ 6″	4	24″	55′ 0″	63′4″	75′0″	83′4″	91′8″	100′0″	120′ 0″	140′ 0″
60,000	19′0″	30′ 3⅛″	8′0″	22′ 3⅛″	4	24″	55′ 0″	63′4″	75′8″	83′4″	91′8″	100′0″	120′ 0″	140′ 0″
75,000	21′0″	30′ 6¼″	8′0″	22′ 6¼″	4	24″	55′ 0″	63′4″	75′0″	83′4″	91′8″	100′0″	120′ 0″	140′ 0″
100,000	24′0″	30′11⅜″	8′6″	22′ 5⅜″	4	24″	50′ 0″	63′1″	75′0″	79′7″	91′6″	100′0″	116′ 6″	141′ 6″
150,000	28′0″	34′ 5⅛″	10′5″	24′ 0⅛″	4	30″	54′10″	63′2″	75′0″	83′4″	91′8″	100′0″	120′ 2″	140′ 3″
200,000	32′0″	35′11½″	12′9″	23′ 2½″	6	24″	54′ 1″	62′5″	75′0″	83′4″	91′8″	100′0″	120′11″	141′10″

* This column lists height of tank cylinder up to high water level. The cylinder actually extends 3″ higher.
† The bottom of this 5000 gallon tank is a segment of a 9 ft. radius sphere.
** Radial bevel of columns of 4 column towers is 1-$^{31}/_{32}$12; of 6 column towers 1:10.
†† Towers of heights other than those listed are available.

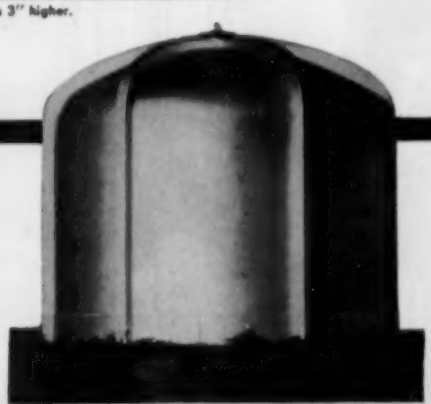


TABLE VI—STEEL RESERVOIRS

Capacity in U. S. Gallons	Diameter	Height
50,000	20′	21′ 6″
60,000	22′	21′ 6″
75,000	24′	22′ 6″
100,000	26′	25′ 6″
150,000	30′	28′ 9″
200,000	34′	29′ 9″
250,000	38′	29′ 9″
300,000	42′	29′ 3″
400,000	46′	32′ 6″
500,000	50′	34′ 6″
750,000	60′	35′ 9″
1,000,000	70′	35′ 0″
1,500,000	80′	40′ 3″
2,000,000	95′	38′ 3″
2,500,000	110′	35′ 6″
3,000,000	120′	35′ 9″
4,000,000	130′	40′ 9″

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R. D. COLE MANUFACTURING CO.

Est. 1854

Tanks, Towers, and Steel Plate Work

NEWNAN, GA.

5,000 TO 2,000,000-GALLON WATER TANKS

All shapes and sizes—The R. D. COLE MANUFACTURING CO. has developed a complete line of elevated steel tanks for water supply, both for domestic service and sprinkler requirements, ranging in capacity from 5,000 to 2,000,000 gallons.

The designs include the standard Hemispherical Self-supporting Bottom, the "Cole Ovaloid," Standpipe and many individual styles involving architectural treatment to satisfy local conditions, or to provide special shapes for advertising purposes.

STORAGE TANKS

Pressure tanks for storage of gas from digesters at sewage disposal plants so that excess output at peak loads can be used during off-peak periods. Chemical storage tanks, hot water storage tanks, tanks for bulk storage of oils and gas.

Designs Available for Any Service

500,000 Gallon "Cole-Shallow Depth" Tank

CONSTRUCTION FACILITIES

Fabricated Steel Plate—The R. D. COLE MANUFACTURING CO. has a fully equipped plant for the fabrication of riveted or welded steel plate. In addition to the construction of its regular line of horizontal return tubular boilers, oil storage tanks, tubular heaters, etc., the company is prepared to construct special tanks and apparatus of any specified metal plate.

Alloys and Lining for Processing Apparatus—The facilities and experience of the company enable it to fabricate special apparatus of all kinds for the processing industry using alloy steel plates, stainless steel, nickel-clad steel, etc., or linings such as lead, tin, nickel or Monel.

flowing from the tank away from the pumping station. The pressure losses at points between tank and pumping station are smaller than before because this district is being fed from two ends. This results in shorter travel, smaller velocities and greatly reduced friction losses. At points beyond the tank friction losses are the same as before but pressure is increased because the water is coming from the tank at a high elevation.

The conditions noted prevail approximately during the peak hours when use exceeds pumpage. After the peak is past and pumpage exceeds use, during night hours, the pressure approaches the line AD which represents conditions just as the tank is filled. The lines AC, DC and DE will be lower as the tank is depleted; and when an empty tank begins to fill the line AD will be much steeper.

The above illustrates the general result when storage is added without increasing the distribution feeders. Storage is an alternative to new and larger pipes and pumps.

Location and Height

A number of local conditions enter into the question of the best location for storage and the most suitable elevation. Storage is almost always an addition to an existing plant and therefore it must fit existing facilities as well as possible. The following general principles should be guides:

1—Storage should be reasonably close to heavy peak drafts of water and on the opposite side of such points from the pumping station.

2—Elevated storage at the pumps helps the pumps but does not add to the capacity of the distribution system, which involves more than half the cost of the average water works.

3—Elevated storage on the opposite side of heavy draft permits water to be fed from both ends of the distribution system, thus nearly or quite doubling the capacity of the feeders.

4—The top of the stored water will necessarily be slightly below the maximum existing pressure plane of the pumps; but must *not* be too high to fill in the night hours of a peak day. The depth should be as shallow as reasonably possible; 20 to 25 feet is common.

5—The value of storage is largely lost when too far away. Costly pipes can overbalance the advantage of storage.

Amount of Storage Required

Fig. 3 shows the amount of storage necessary upon a maximum day to reduce the pumpage to a constant rate throughout the 24 hours of such a day. It also shows the effect of various lesser amounts of storage in reducing the peak hour requirement. The curve shown on the diagram is a median line between the extremes represented by dots upon the diagram. Each dot represents a computation for one of the five cities shown in Table I. It will be observed that a large benefit in pumpage reduction can be secured from a relatively small installation in storage.

These data indicate upon the average that 20 per cent of the maximum day in elevated storage may be expected to reduce the maximum hourly peak about 45 per cent. Or, expressed in another way, in the five cities studied 30 gallons per capita in storage might be expected to reduce the maximum hourly pumpage peak rate 126 gallons per capita if the storage is most effectively used.

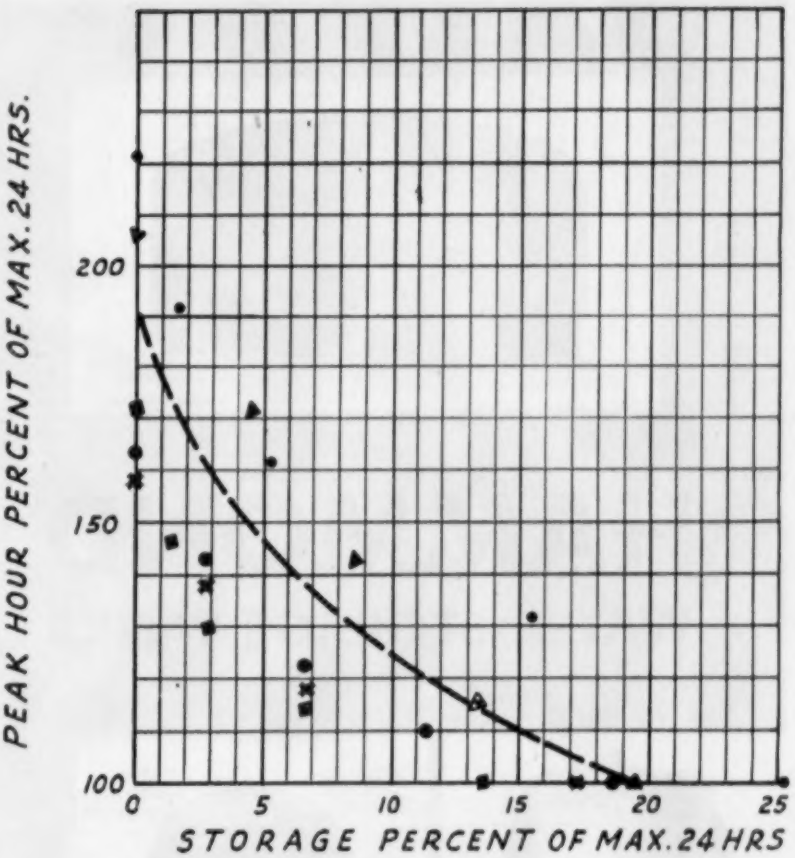


Fig. 3.—Effects of Storage on Pumpage Peaks in Five Cities
(Expressed in per cent of max. 24 hr. pumpage on maximum demand days. Each symbol of different design represents one of the five cities covered in Table I.)

In determining how much elevated storage shall be built, consideration is properly given to the existing installations in water supply facilities. The system as a whole must be designed for the maximum requirements for water, which must include the maximum requirements for fire protection if good fire protection service is furnished. In each case a proper installation is a coordination between elevated storage, water supply, pumps and distribution pipe facilities, so adjusting these facilities means that adequate service is furnished at least cost.

Fire Protection

One of the most important benefits from elevated storage is the ability to respond instantly to the heavy draft of water required for fire protection. In the smaller towns this furnishes an especially valuable service while pumps are being started, for many such systems pump intermittently.

In Table 2, column 4, there is shown the rates at which water should be furnished to comply with recommendations of the National Board of Fire Underwriters for cities of various sizes. For comparison there is also shown the average and maximum rates of pumpage based upon the average of the five cities shown in Table 1.

For the smallest town the fire demand is nearly five times the peak hour use, and pumps and distribution system must be designed accordingly without storage, bearing in mind that about 50 per cent above the average domestic demand plus the fire demand must be accommodated.

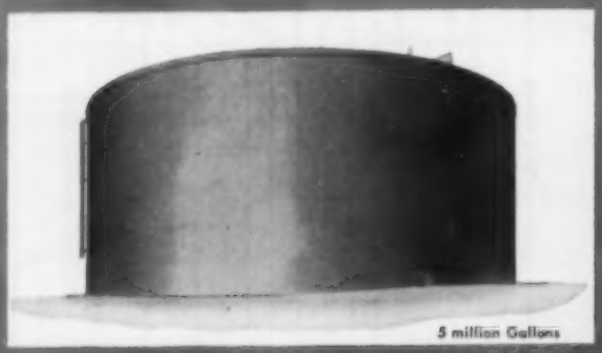
In towns over 25,000 the peak hour and the fire demand are about equal. In cities of 100,000 or more the combined domestic and fire demand is less than the domestic peak hour demand, and fire protection ceases to be a controlling factor so far as rates of pumpage are concerned.

It should be borne in mind that adequate fire protection provides for very rare emergencies. Likewise, the maximum storage for domestic peak hours is needed on only a few days in exceptional years, and usually an installation contains a reserve for future growth. Therefore an installation proportioned for domestic service is an important addition to the fire protection. It alone provides ample water for the great majority of fires, and the first and more important water in exceptional fires. Its great value is its readiness to serve.

Types of Distribution Storage

Various types of distribution storage are best adapted to special conditions. These types are summarized as follows:

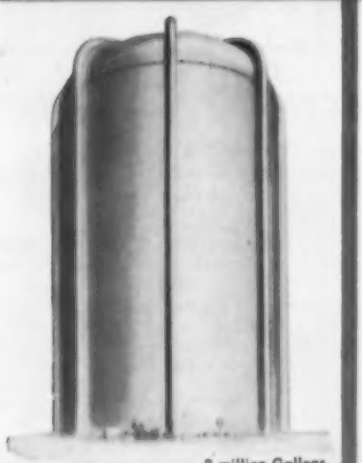
1—Most of the cities in this country are relatively flat and the elevated tank of steel is most widely used. It is now built in shallow depths so that all the water is stored at sufficient elevation to be useful. Sizes as large as 2 mg. are available. Recent designs present a very pleasing appearance.



5 million Gallons

100,000 Gallons

HAMMOND
WATER STORAGE TANKS



2 million Gallons

500,000 Gallons

Hammond Water Storing and Processing Vessels are built to all standard codes and specifications including those of the American Water Works Association, Associated Factory Mutual Fire Insurance Companies, the National Board of Fire Underwriters, the Factory Insurance Association.

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TABLE 2
Rates of Pumpage Required in Cities of Various Sizes

Population	1 Ave. MGD. at 100 Gals. per Capita 100%	2 Probable Peak 24 Hrs. MGD. 167%	3 Probable Peak Hr. MGD. 308%	4 Max. Rate for Fire Protection MGD.	5 Storage for Hourly Peaks 20% of Max. Day
1,000	.1	.17	.31	1.44	.033
2,000	.2	.33	.61	2.15	.066
4,000	.4	.67	1.24	2.86	.134
10,000	1.0	1.67	3.08	4.30	.334
25,000	2.5	4.66	8.64	7.15	.932
60,000	6.0	10.00	18.50	10.00	2.00
100,000	10.0	16.70	30.80	12.90	3.34
200,000	20.0	33.40	61.60	17.20	6.68

2—There are some situations where elevated ground is available but not high enough for a concrete reservoir on the ground. In such situations circular steel tanks up to 40 to 60 ft. high and of large capacity can be built for less than half the cost of elevated tanks per unit of capacity. Such tanks can sometimes be scattered at more than one location with beneficial results. For the higher of such tanks all the water may not be fully useful but it furnishes a cheap support for the more useful elevated water.

3—Many cities are so fortunate as to have elevated ground sufficiently high to accommodate elevated reservoirs. These cost about half as much as most elevated tanks. Most recent reservoirs are covered, built of reinforced concrete buried in the ground, and have long life with small maintenance costs. Reasonable cost favors large capacities. In some installations the entire fire protection water is stored in addition to domestic requirements. As much as 100 to 300 gallons per capita is stored in some cities.

4—Where elevated ground is not available it is sometimes economical to build concrete reservoirs or steel tanks on the ground, fill them at night with water bled from the mains and repump stored water back into the mains by remote controlled or automatically controlled electric pumps. The capitalized cost of repumping should, of course, be charged to the installation. In cost comparisons such pumping may be less costly than might be thought if operation is required only a few hours per day during a limited portion of the year.

Operation of Storage

Money should be conserved for use. Likewise water stored should be conserved so that it will be available when needed. There is little use for storage during about 80 per cent of the normal year. With storage it becomes possible to run pumps at a nearly uniform rate, with attendant advantages of economy, and on normal days to utilize only a few feet of the upper part of the storage. The storage should only be materially exhausted during the peak hours of the heavy pumpage days, and always refilled before morning.

Water works men are now more firm than ever in the belief that storage on the distribution system pays its way in the reliability and economy of water service.

Fire Hydrant Flow Gage

by A. A. HIRSCH
State Dept. of Education, Baton Rouge, La.

Of the several methods in vogue for hydrant flow measurement, namely the special pitot tube-gage combination, the stream trajectory, the short tube with terminal orifice, and the velocity head reading by means of a pressure gage on a closed cap, the last named is the one most generally employed by reason of its simplicity in principal and equipment.

The Procedure

In determining flow from a fire hydrant by the pressure gage method all that is needed is to connect an accurate gage to the closed nozzle, and discharge the hydrant through the other nozzle. The flowing nozzle may be considered as a "short-tube"

Figure 1.—Dial of pressure gage calibrated to read directly fire hydrant flow from a 2½-inch nozzle.

and its flow calculated from the usual orifice formula, but using an orifice coefficient of 0.9 instead of the familiar 0.61 which holds for a sharp edged orifice. Thus

Flow (cu. ft./sec.) = C A V where C = fire hydrant orifice coefficient = 0.9.

$$A = \text{area of nozzle (sq. ft.)} = 0.785 \times \frac{\text{Diameter}^2_{\text{(inches)}}}{144} = 0.00545\ \text{Diameter}^2_{\text{(inches)}}$$

$$V = \sqrt{2\ g\ h_{\text{ft. water}}} = \sqrt{2 \times 32.16 \times 2.31 \times \text{Pressure}_{\text{psi.}}}$$ the pressure reading being taken off the closed nozzle

$$= 12.2\sqrt{\text{Pressure}_{\text{psi.}}}$$

Substituting in the first equation:

$$\text{Flow (gpm.)} = 7.48 \times 60 \times 0.9 \times 0.00545\ \text{Diameter}^2 \times 12.2\sqrt{\text{Pressure}_{\text{psi.}}}$$

$$= 27\ \text{Diameter}^2_{\text{(inches)}}\sqrt{\text{Pressure}_{\text{psi.}}}$$

This is the familiar form commonly used to calculate the discharge from a fire hydrant.

Ordinarily the 2½-inch nozzle is used, as the 4- or 4½-inch nozzles do not conform with accuracy to a simple formula. Substituting the value of 2½ inches for the diameter in the above formula there results

$$\text{Flow (gpm. through 2½ in. nozzle)} = 27 \times 2.5^2 \times \sqrt{\text{Pressure}_{\text{psi.}}}$$

$$= 168.7\sqrt{\text{Pressure}_{\text{psi.}}}$$

from which the discharge through a 2½-inch hydrant nozzle may be conveniently calculated.

The Self-Calculating Gage

Inasmuch as a given velocity head on the pressure gage corresponds to a fixed discharge the gage may be calibrated to read this flow directly and thereby obviate the need for calculation. A dial so calibrated is illustrated in Fig. 1. By marking off a dial in this manner the gage may be used in hydrant flow studies to facilitate discharge adjustments and to enable flow evaluation on the spot without calculations or conversions. Fig. 1 may also be used as an approximate solution to the hydrant formula for a 2½-inch nozzle rather than perform the numerical substitutions.

The accuracy of the pressure gage should be checked on a cold test apparatus, especially in the low pressure range below 500 gpm. where slight inaccuracy causes relatively large errors in the indicated discharge. If the test gage is off the needle position may be reset, the linkage between hollow spring and sector adjusted as required, or a calibration curve drawn to show the true pressure corresponding to any gage reading. From Fig. 1 it will be noted that below a flow of about 250 gpm. the type of pressure gage as illustrated is inapplicable since it fails to deflect.

BETHLEHEM STEEL

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WATER-STORAGE TANKS
TAR-ENAMELED WATER PIPE
TAR-ENAMELED SEWER PIPE

Water-Storage Tanks

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DESIGN • FABRICATION
ERECTION

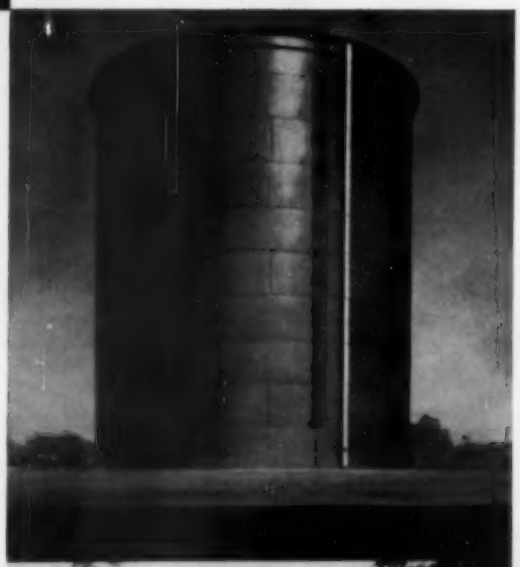
The next time you are in need of holders for the storage of water, gas or oil, put your requirements up to Bethlehem.

Bethlehem is at your service with more than fifty years of experience in furnishing all types of storage tanks to municipalities. We are equipped to handle each job from beginning to end — from design of the structure to fabrication and erection of the steel.

Bethlehem Tanks are furnished to A.P.I. or A.W.W.A. specification, and generally are of welded construction. Riveted construction can also be used, if desired. Bethlehem Tanks are economical to maintain, and are dependable in every way.

In addition, Bethlehem specializes in all types of fabricated steel and platework for municipal use: buildings, bridges, viaducts, large-diameter pipe, stadium seating, floodlight towers, and other steelwork.

For full details we suggest you call the Bethlehem sales office nearest you.



Bethlehem fabricated and erected this 76-ft welded standpipe at Akron, Ohio. Capacity, 2,000,000 gal.

This Bethlehem-built, 423,000-gal welded standpipe is located at Lynnfield, Mass. It is 113 ft high.

This water reservoir of all-welded construction, 85 ft in diameter and 25 ft high, has a capacity of 1,000,000 gal.

For information about Bethlehem Tar-Enameled Water and Sewage Pipe, kindly turn to the following three pages

You Can't Beat Steel Pipe For Strength

BETHLEHEM STEEL

Bethlehem Tar-Enameled Steel Pipe is widely used for water and sewage service because of its resilience, its resistance to shock and corrosion, and its leakproof joints. But the most important reason for its popularity is its great strength, which is evident in the chart below.

The chart shows the theoretical working and bursting pressures for various pipe diameters and thicknesses. The pressures shown are based upon the use of steel conforming to ASTM Specification A-283, Grade B, having a minimum tensile strength of 50,000 psi. When exceptionally severe internal working pressures are encountered, the use of higher strength steel is recommended. If you would like to have further information, kindly call or write the Bethlehem sales office most convenient to you.

THEORETICAL INTERNAL PRESSURES OF STEEL PIPE

	1/4 in.			5/16 in.			3/8 in.			7/16 in.			1/2 in.		
DIAM	WT LB/FT	MAX WRK PRESS PSI	MIN BURST PRESS PSI	WT LB/FT	MAX WRK PRESS PSI	MIN BURST PRESS PSI	WT LB/FT	MAX WRK PRESS PSI	MIN BURST PRESS PSI	WT LB/FT	MAX WRK PRESS PSI	MIN BURST PRESS PSI	WT LB/FT	MAX WRK PRESS PSI	MIN BURST PRESS PSI
18	49	445	1390	61	555	1735	73	665	2080	85	775	2430	96	890	2780
20	54	400	1250	68	500	1560	81	600	1875	94	700	2180	107	800	2500
22	63	365	1135	78	465	1420	93	550	1700	109	640	1985	124	730	2270
24	69	335	1040	86	420	1300	102	505	1560	119	585	1820	136	665	2080
30	86	270	835	108	340	1040	129	405	1250	150	475	1455	170	535	1670
36	106	225	695	130	280	870	155	340	1040	181	395	1210	206	445	1390
42	119	195	595	148	240	745	177	285	890	206	335	1040	234	380	1190
48	137	170	520	171	210	650	203	250	780	236	290	910	268	330	1040
54				192	190	580	230	225	695	267	260	810	303	295	925
60				214	170	525	255	200	625	296	235	730	336	265	835
72							309	170	520	359	195	605	408	220	695
84							357	145	450	412	170	520	470	190	595
96	The recommended minimum wall thickness is approximately the pipe diameter divided by 165. Pipe having this diameter-thickness ratio, when backfilled and properly tamped, will withstand any depth of cover. For buried pipe, the recommended minimum thicknesses are shown immediately above heavy black line.									470	145	455	539	165	520
108													*611	150	465
120													*669	135	415

Based on use of ASTM A-283, Grade B Steel, 50,000 psi min. ultimate tensile strength.
*Under certain conditions stiffeners may be required to reduce deflections.

$P = \frac{t \times Ts}{r}$ | P = internal pressure, psi | t = thickness, in. | Ts = allowable unit stress = 60% x 27,000 (yield point) = 16,000 psi | r = radius of pipe, in.

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Bethlehem

TAR-ENAMELED STEEL PIPE

The most dependable and economical for Water and Sewage Lines

Here are six good reasons for using Bethlehem Tar-Enameled Steel Pipe wherever economy and dependability are essential:

BEAM STRENGTH

It is made from high-quality steel plate. Multiple 40-ft lengths up to 120 ft have been handled without damage to the pipe. This demonstrates its great beam strength which is important in emergencies such as flash washouts.

CORROSION-RESISTANCE

Bethlehem Steel Pipe is lined and coated with a smooth layer of coal-tar enamel, meeting AWWA Specifications. The enameled pipe is impervious to corrosion and incrustation and has flow-coefficients as high as 150.

SHOCK-RESISTANCE

Bethlehem Steel Pipe is designed with a safety factor of about 4. This makes it resistant to water-hammer, as it can safely carry a load of nearly four times the working pressure. See the chart on the next page.

LEAKPROOF JOINTS

A tight line can be made by joining pipe lengths with mechanical couplings, or by welding or riveting. Washouts due to floods or other causes are usually spanned without failure of the joints.

RESILIENCE

Bethlehem Steel Pipe is extremely resilient. When subjected to surface vibration caused by heavy vehicular traffic, it will yield slightly, unlike the rigid types of pipe which frequently fail under the same conditions.

40-FT LENGTHS

Available in 40-ft lengths and in all diameters from 18 in. ID to the largest permitted by common carriers. Only 132 joints are required per mile as compared to 300 or more required by pipe of other materials. This results in big savings in pipe-laying costs.

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Pitometer Surveys of Water Systems

Surveys and flow tests locate water leaks, theft, and system defects

by W. D. HUDSON

Asst. Chief Engr., The Pitometer Associates, Inc., New York, N.Y.

This paper was presented at the 22nd Annual Water Plant Operators' Conference in Springfield, Ill., and is published in the Reference & Data Edition of Water & Sewage Works with permission.

BEFORE discussing Pitometer surveys, it might be well to explain the word "Pitometer". It is a coined word derived from "Pitot" and "meter." A Pitometer is a reversible Pitot tube. To most water works men, the word Pitometer suggests an engineering service for water distribution systems. The Pitometer instrument combined with The Pitometer Associates' fifty years of engineering experience in the field of water distribution, forms the basis for distribution system surveys.

There are three principal types of Pitometer surveys:

1. Pitometer water waste surveys
2. Pitometer distribution or engineering studies
3. Pitometer trunk main surveys

Water Waste Surveys

The water waste survey is designed to locate underground leakage and waste in a distribution system, and to make a complete accounting to all water that is supplied to the system.

The first step in making a survey is to check any long supply mains for leakage by simultaneous measurements; that is, Pitometers are inserted in each end of the main and the rate of flow is measured simultaneously. If a discrepancy exists between the two measurements, it indicates leakage or loss of water along the supply main. The measurements are repeated, using shorter sections, until the point of leakage or unauthorized use is located.

Next, the pumping equipment is tested for efficiency, These tests very often result in finding inefficient pumping equipment that can be repaired or replaced. Often the saving in fuel cost alone during the first year will pay for the cost of repairing or replacing the faulty equipment, and will enable the water department to provide better service.

Then the master meters are tested for accuracy. This is important as, at times, an inaccurate master meter may be the sole cause of the unaccounted-for water.

After the master meters are tested, a measurement is made of the total water consumption of the city during a twenty-four hour period. Pitometer devices provide continuous recordings of the rate of flow; therefore the maximum rate of use, the minimum rate of use, or the rate of use at any time during the day can be obtained from this measurement. By comparing the total amount of water used during the twenty-four hour period with the minimum rate of use during the night, it is possible to tell if any large amount of leakage exists in the system.

The next step in the survey is to divide the system into Pitometer districts. These districts are laid out according to conditions existing in the system, and vary as to size in every system. Usually the districts either are residential, commercial or industrial. After the districts have been selected, a Pitometer is inserted in a large trunk main that will supply the district, and all other valves along the boundary of the district are closed. This practice isolates the district from the rest of the system, except for the large main into which the Pitometer has been inserted. A typical distribution system layout is illustrated in Fig. 1.

Pressures are measured before any valves are closed and also after the valves are closed, to be certain that the district has ample feed main capacity. Special attention is given to the possibility of fire breaking out in the district and arrangements made so that, if a fire does occur, additional valves can be opened rapidly—leaving no possibility of inadequate water for fire fighting purposes due to closed valves.

The district measurements show the total consumption of the district for a twenty-four hour period, the rate of flow at any time during the twenty-four hours, as well as the maximum flow and minimum night rate of flow. Taking into account any industrial consumption in the districts, the ratio of the total consumption (water actually used during the twenty-four hours) to the minimum night rate indicates the condition of the system as to leakage or unaccounted-for water. If this ratio exceeds 40 per cent, there is sufficient leakage to justify further investigation.

The district measurements show sections of the city in which leakage exists. If the value of further investigation is indicated by the district measurements, this work is done at night or during the period of minimum flow.

The subdivision or investigation of the night rate is accomplished by inserting a Pitometer on a small (usu-

Fig. 1—TYPICAL water distribution system isolated for pressure measurement

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In thousands of communities, Transite Pipe—with its advantages of joints that remain tight and flexible, its corrosion resistance, and immunity to tuberculation—provides low-cost water transportation that requires little, if any, maintenance. Transite lines do not have to be cleaned, lined, or replaced because tuberculation has reduced their original capacity. Reports from communities all over the country prove that Transite's asbestos-cement structure provides economies that continue through the years.

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Class (maximum recommended working pressure, psi)	Equivalent head, feet of water	Nominal inside diameter, in.						
		4	6	8	10	12	14	16
		Pounds per linear foot including coupling and rubber rings						
100	231	7	11	16	22	30	39	51
150	346	8	13	20	32	43	58	73
200	462	10	16	24	38	53	71	93

R-S
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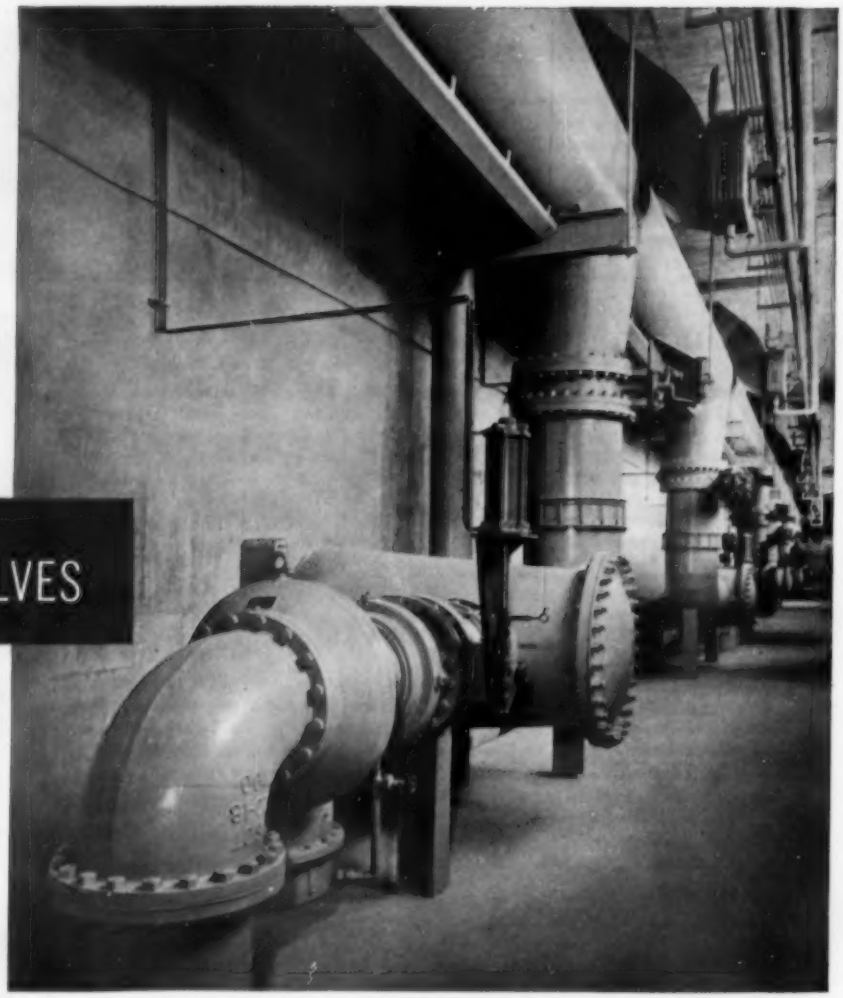

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Positive closure in R-S Rubber-Seated Valves is obtained by wedge-type closure of the disk within a one-piece rubber seat. Tough, flexible rubber seals the entire disk seat – including the area around the shaft bosses. Supervised testing of a six inch R-S Rubber-Seated Valve proved that after 6,000 closings the valve was still giving positive shutoff at 100 psig water.

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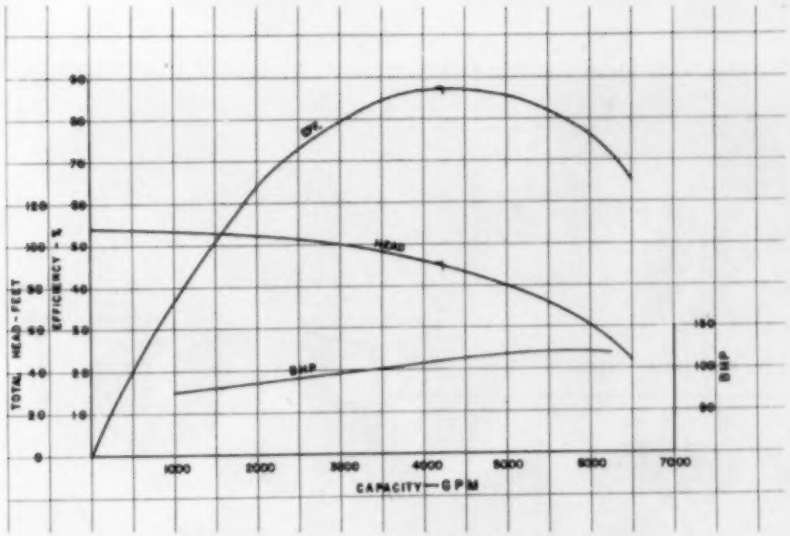


Fig. 2—EXAMPLE of performance curves for centrifugal pumps

ally 6-in.) main, then the valves are closed at each end of the block and a hydrant is opened to see if the water is shut completely off. If the water is not off, the valves are flushed, that is, opened and closed until they hold tightly. Then the feed valve is opened and any flow in the block is recorded on the Pitometer. This procedure is repeated for the adjacent blocks, until the area to be investigated is entirely covered. This results in the measurement of the rate of flow in each block. As this work is done at night, theoretically there should be no flow of water unless there is water escaping through underground leaks or is waste in homes.

Block measurements of the minimum night rate of flow show exactly in which block there is leakage or use of water. The blocks are checked for leakage by using listening devices. Individual services are checked with an aquaphone, and the mains are checked with a geophone. There is no substitute for experience in actually locating the leaks, and a well trained engineer can tell exactly where to break the pavement to reach a leak.

The primary purpose of the water waste survey is to locate all leaks in the system. However, this survey is of equal value to the water department in many other ways. It is absolutely essential to completely shut off the smallest possible areas, and about 80 per cent of the valves in the system are operated. This results in the finding of closed, broken or defective valves. A complete record is kept by the field engineer, recording the time each valve was operated, the direction and number of full turns required to close, and the condition of the valve. Thus a record is obtained of valve operation and of the condition of most of the fire hydrants.

Every valve that is left closed in a system creates two dead ends. On a trunk main, a closed valve may seriously affect the operation of the entire system. On a distribution main, it may be the cause of low pressure, inadequate water for fire protection, or possibly the cause of bad water.

Because it is necessary to obtain tight shut-offs, any connections are discovered that are different from those recorded on the map of the distribution system. The may is thoroughly field-checked and the connections proven. This is important in any system, and are especially so where the maps were developed on the knowledge handed down and plotted possibly 10 to 50 years after the actual installation was made.

Another and very important by-product of the water waste survey is the use of district measurements to obtain data on the distribution of water consumption in the system for design purposes. These water consumption measurements can be coordinated with the population (obtained from census data), and the actual per capita consumption can be computed for the various sections of the distribution system. Also, the ratio of maximum rates of consumption to the average rate of consumption is known. By taking into account the total consumption for the entire system on the day the individual districts were measured, it is possible to develop all maximum water quantities necessary for design purposes.

In addition to the work already described, all meters larger than 3-in. are tested in place for accuracy. Also many small meters that are not registering are discovered during the leak investigation. At the conclusion of the survey a detailed report showing the results of all measurements is submitted to the Department.

As the result of eliminating underground leakage, finding and opening closed valves, and increasing the efficiency of the pumping equipment, the system often is materially improved and the need for expensive reinforcing mains is eliminated. Leakage is expensive, as plant capacity, main capacity, dollars in power, and chemical costs are wasted.

Distribution Studies

Pitometer distribution studies are made to determine how an existing water system functions and also, if the system is adequate to meet present needs and probable future requirements that will be placed upon it as it is expanded.

As in a water waste survey, the distribution system is divided into districts, and the water consumption is measured in each district for a twenty-four hour period. Then, using census data as a basis, a population study is made for the system as a whole and for each of the Pitometer districts. By coordinating water consumption with population data, the probable future water quantities are established for design purposes.

In making a complete Pitometer analysis of a distribution system, several types of flow tests are made. Most of these tests require both special equipment and trained personnel. Following is a brief discussion of the purpose of each of these tests and a brief description of how some tests are made.

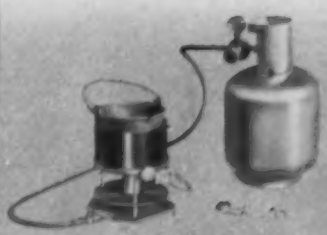
Testing Pumping Equipment

The purpose of testing pumping equipment is to determine the efficiency with which the equipment performs its work. The centrifugal pump is used in most water systems at the present time. Usually these pumps are electrically driven or are powered by a diesel motor. In some larger cities steam turbines are used.

A centrifugal pump is designed to work under rather rigidly fixed conditions and any appreciable variation from these fixed condition is accompanied by a decreasing efficiency. Too often the only demand made on a centrifugal pump is that it pump water: no attention is paid to the *efficiency* with which it does its work.

A typical centrifugal pump curve is shown in Fig. 2. It will be noted that the greatest efficiency for this particular pump, which is about 87 per cent, is secured when the head is approximately 90 feet and the discharge rate is 4200 gpm; that the efficiency is at least 85 per cent as the

JOINT RUNNERS



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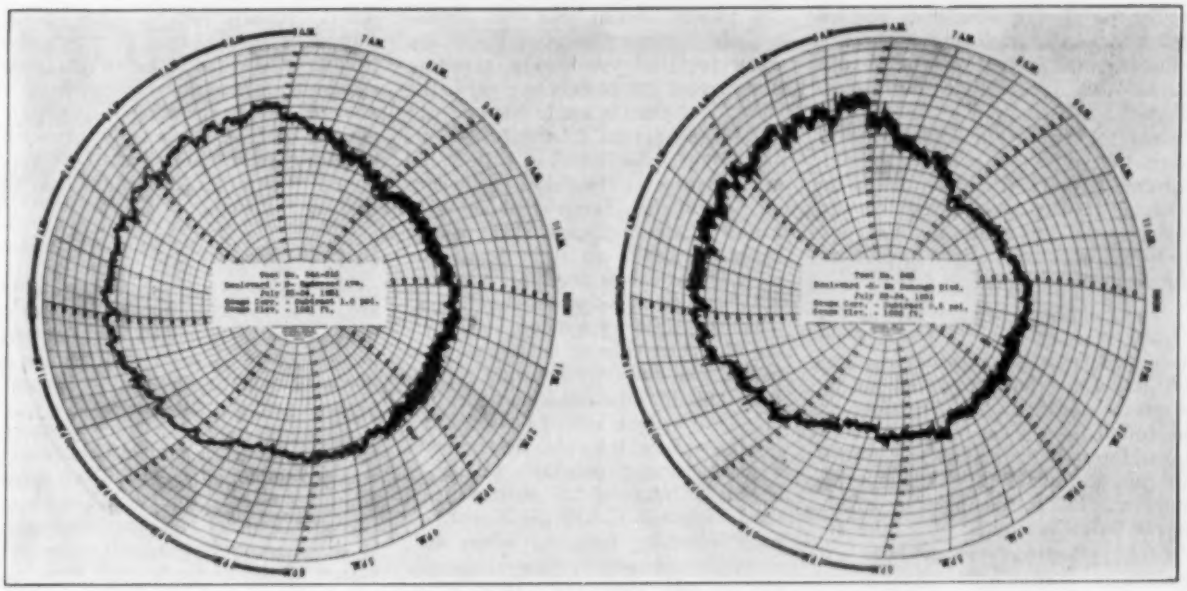


Fig. 3—TYPICAL pressure charts used to determine hydraulic gradient

head varies between 95 feet and 78 feet and the discharge varies from 3600 gpm to 5100 gpm. It will be noted alsot hat ift he head drops to 60 feet the discharge will increase to 6000 gpm, but the efficiency will be only 75 per cent; or if the head is increased 10 feet to 105 feet the pump will put out 1750 gpm and be only 58 per cent efficient. If the head is raised an additional 2 psi, the pump will pump no water. Tests made on centrifugal pumps have revealed that, during certain times of the day and under certain conditions, a centrifugal pump may not pump any water into the system, but merely churn the water.

It can readily be seen that each centrifugal pump must be designed for the particular job it is to do, and that in most cases it is false economy to use a pump that does not have the right characteristics for the job. Often an efficiency test on a pump will bring to light conditions that can be corrected with a minimum of expense; when this is done, it will greatly improve the operation of the entire distribution system.

There is an excellent technical paper discussing this subject, prepared by Homer E. Beckwith, District Manager of the Pitometer Associates, Inc. (See "Centrifugal Pumps—Notes on Selection of Pumps and Checking Pump Efficiencies." *Water & Sewage Works*, R & D Edition, page R-73, 1951.)

Flow Gaugings

Flow gaugings are made in the various trunk mains to determine how water circulates through the trunk main system; to determine if the rate of flow in any of the trunk mains is at an excessively high velocity; and to determine if any trunk mains are carrying less water than normally would be expected.

Measurement of the flow of water through the trunk main system is of the utmost importance in the study or analysis of a distribution system. The only feasible way of making this type of test is by using Pitometers. The Pitometer is inserted in the main through a 1-in. corporation cock (as a reversible Pitot tube the Pitometer measure reverse flows in the main). From the Pitometer recorder one can obtain a continuous record of the flow at the gauging point for any period of time that is desired, usually a twenty-four hour period. Thus, at the gauging point, the total amount of water that flows through the main during the twenty-four hours is measured; also measured is the maximum rate of flow and the minimum rate of flow. By making several Pitometer gaugings simultaneously, one can determine exactly how the water circulates through the trunk main system.

Pitometer flow measurements require that special equipment be used by engineers trained to conduct the tests and to interpret the results.

Fire Flow Tests

Fire flow tests are made to determine the amount of water available for fire fighting purposes.

These tests are the one type of distribution flow test that is easy to make and which does not require much equipment. Four dial-type pressure gauges and three hydrant Pitot tubes are all that is needed for most tests. While fire flow tests are rather easy to make, and the computations connected with them are not too difficult, these tests are invaluable to the average water works man in determining whether or not the water distribution system is adequate.

From a fire flow test, the pressure and flow of water available for fire protection at various points in the system can be determined. Also, from the fire flow test, the location of deficiencies can be determined. The National Board of Fire Underwriters' or its affiliates have made fire flow tests in most cities. These tests can be re-run. If there has been no improvement in the system, and if there is a considerable change in the test results, it would be a good indication that something is wrong or that the system has become overloaded at that point. Following is a brief description of the procedure in making a fire flow test.

At the point on the distribution system where the amount of water available for fire protection is to be determined, place a gauge on a fire hydrant. Then place a hydrant Pitot gauge in the nozzle of a second hydrant; or a pressure gauge can be attached to the nozzle of the second hydrant. This pressure gauge must be in the same plane as the nozzle through which the water is drawn. Observe the pressure on the first hydrant, then open the second hydrant and simultaneously read the pressure on the Pitot first hydrant gauge and on the second hydrant gauge.

In making fire flow tests the hydrants used should form a group that might be used in case of a serious fire in the area under study. Also water should be discharged at a rate sufficient to create a drop in pressure such that it will not be measurably affected by normal fluctuations in the system. It may be necessary to discharge several hydrants simultaneously to obtain sufficient drop in pressure for an accurate test.

The gallons per minute rate of discharge from each hydrant can be determined from the pressure readings on the Pitot gauge related to the diameter of the nozzle. The flow can be found in a table, or can be computed from the formula: $Q = 27D^2P$. In this formula, "Q" is gallons per minute; "D" is the diameter of the nozzle in inches; and "P" is the discharge pressure (velocity head) in pounds per square inch.

To find the approximate amount of water available at 20 psi residual (the minimum to which a system should be drawn) the computations can be made as follows:

$$\text{GPM Discharge at 20 psi. Residual} = \text{Total of Group of Hydrants Opened} + \frac{\sqrt{\text{Residual Press.—20 psi. (Hydts. closed)}}}{\sqrt{\text{Residual Press.—Res. Press. (Hydts. closed) (Hydts. Open)}}}$$

As most of the loss is in the main system, the expected discharge can be calculated more accurately from the Williams-Hazen formula:

$$\text{GPM Discharge at 20 psi. Residual} = \text{Total of Group of Hydrants Opened} + \left\{\frac{\text{Residual Press.—20 psi. (Hydts. closed)}}{\text{Residual Press.—Res. Press. (Hydts. closed) (Hydts. Open)}}\right\}^{0.54}$$

Fire flow tests often bring to light unusual conditions. If a fire flow test has been made and the results are erroneous, investigate for closed valves. Closed valves frequently are found where tests indicate something is wrong in the distribution system.

Loss of Head Tests

Loss of head tests are made to determine the internal condition of pipes; that is, whether they are tuberculated, or if obstructions exist. The results obtained from a Pitometer loss of head test are expressed as the coefficient of roughness "C" value in the Williams-Hazen Formula.

Running a loss of head test requires Pitometers to obtain the velocity; accurate pressure recording gauges (feet of water) to obtain the head; and an engineer thoroughly trained in this type of work.

Pitometer loss of head tests are extremely important in planning design work for the system. The resulting design work can be only as good as the basic data that is used. No one can guess the internal condition of pipe, and visual inspection is of little value in estimating the roughness coefficient. The Williams-Hazen Tables give values of the coefficient that may be expected, based on the age of the pipe. These tables are quite accurate for the type of water in the area in which the tests were made. However, the characteristics of water vary so widely that the only accurate way to determine the roughness coefficient of pipe is to make a loss of head test.

Loss of head tests also determine if a main-cleaning program will be a benefit by returning the mains to near their original C-130 coefficient. A main cleaning program often will eliminate the need, or delay the necessity for reinforcing the system.

Pressure Recordings

Pressure recordings are made to determine the fluctuations of pressure in the distribution system.

At critical points in a water distribution system, pressure recordings should be considered a necessity. This is one way in which a constant check can be kept on the system. By comparing the pressure gaugings from time to time it can readily be learned if the pressure pattern is changing. If there is a sudden reduction in pressure, and if it continues to stay lower, there is a good possibility that a sizable leak has developed. If the pressure drops gradually, it is probable that the system is becoming overloaded or that the trunk mains are losing their carrying capacity. Permanent seven-day pressure recording gauges should be installed in all pump stations and, usually, in each fire station in the city. As a rule, the fire stations are fairly evenly spaced throughout the city and are a good location in which to install pressure gauges.

If there are complaints regarding a particular part of the system, it is a good policy to run twenty-four-hour pressure gaugings, usually at two points simultaneously. One point should be in the area in which the trouble exists, and the other point should be where the feeder main is made to supply the area. By comparing the gauging charts, the pressure loss between the points can be determined. This procedure might help to find the trouble.

Hydraulic Gradient

Hydraulic gradient measurements are made to determine the pressure drop between various critical points in the system. This type of test is a necessity in order to make an analysis of a water distribution system.

The test is made by placing pressure recording gauges at the critical points and by obtaining the flow at these points by using Pitometers. The pressure gaugings are run simultaneously. It is necessary to determine the elevation of the gauge at each gauging point. See typical charts; Fig. 3. Using the elevation, converting the pressure at the gauging point into feet of water (by multiplying the pressure in psi by 2.31), and adding this value to the elevation, the water level can be determined at each point. These data can then be plotted on suitable graph paper, and the results will show the hydraulic gradient.

Fig. 4 illustrates the hydraulic gradient across a part of a water system. On examination of this chart, it may be noted that the slope is much steeper in the first section of the main. It is obvious that the large loss of head occurs from the pumping station to the first gauging point. The logical step to reinforce this system is to provide additional main capacity from the pumping station to a point in the system that will materially reduce the loss of head in the first section of the hydraulic gradient.

From the data obtained in these tests, a complete analysis is made of the existing system. The weak points and strong points are determined. The tests frequently bring to light such conditions as closed valves, air pockets, badly tuberculated mains, or other deficiencies which can be corrected; thus enabling the system to operate at maximum efficiency without major improvements.

If improvements and reinforcing mains are needed, then information regarding the system obtained in making the tests, combined with the complete data available, will form a sound basis for the design of reinforcements.

Trunk Main Surveys

Trunk main surveys are made to determine how water circulates through the trunk main system. the

mains which carry their share of the water, the mains which are overloaded, the mains which are not operating efficiently, and the internal condition of pipes.

In making a trunk main survey, the trunk main system is divided into test sections. Usually a test section extends between two principal trunk mains. By simultaneously making several Pitometer gaugings, the amount of water entering the section of main to be tested is measured, the take-offs from these trunk mains through principal feeder mains are measured, and the flow out of the test section is measured. Then the adjacent section of trunk main is tested in the same manner. This procedure is repeated until flows through the entire trunk main system have been measured.

By taking into account the pumpage during the days on which tests are made, and by establishing a relationship between the tests by repeating the trunk main gauging common to two test sections, it is possible to simulate the condition of making all tests during a single day. Thus it is determined exactly how the water circulates through the trunk main system.

The trunk main survey is designed principally for large cities having an extensive trunk main system.

This article very briefly covers the different type of Pitometer surveys and flow tests that are used in analysis of a distribution system. The water departments in large cities seldom maintain sufficient equipment and trained personnel to make a complete study of their distribution systems. It is not economically feasible to do so. It is economical to consult occasionally with an engineering firm about special problems, and to obtain the benefits of experience and technology from men who constantly work on water distribution problems. With present material costs and high taxes, it is essential that improvements involving large expenditures shall be thoroughly engineered. ***R&D***

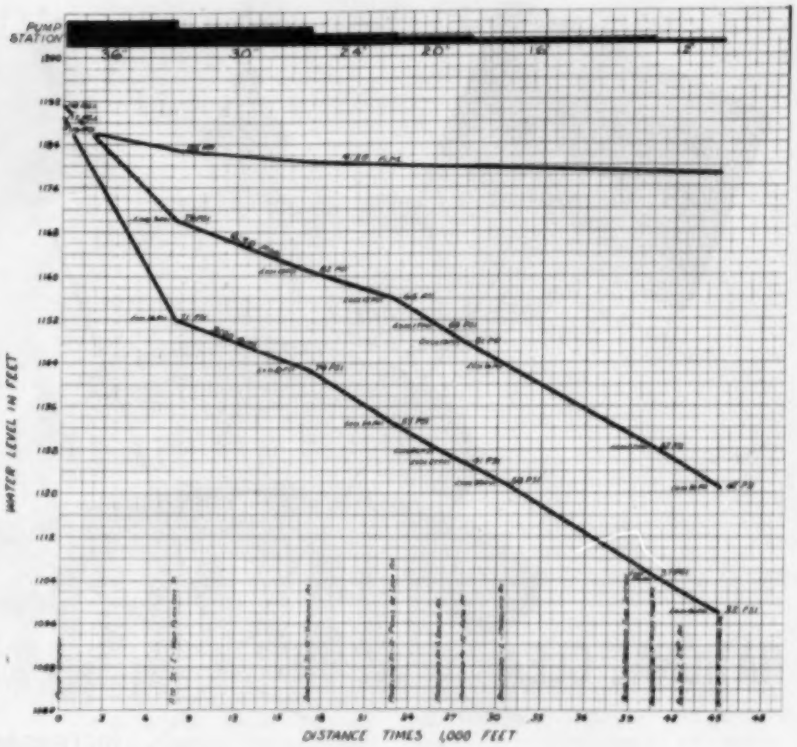


Fig. 4—HYDRAULIC gradient lines of a distribution system

WHAT LEAKS COST

SIZE OF OPENING	AIR		STEAM		WATER	
	Number of Cu. Ft. Wasted per Month 100 Lbs. Pressure	Total Cost of Waste per Month @ 15¢ per M Cu. Ft.	Number of Lbs. Wasted per Month 100 Lbs. Pressure	Total Cost of Waste per Month @ 60¢ per M Lbs.	Number of Gallons Wasted per Month 40 Lbs. Pressure	Total Cost of Waste per Month @ 16¢ per M Gals.
1/2"	17,798,400	$1,779.84	805,000	$483.00	1,231,000	$192.00
3/8"	9,979,200	997.92	460,000	276.00	692,400	108.00
1/4"	4,449,600	444.96	203,000	121.80	307,700	48.00
1/8"	1,114,560	111.46	50,500	30.30	76,900	12.00
1/16"	278,640	27.86	12,750	7.65	19,200	3.00
1/32"	69,552	6.96	3,175	1.91	4,800	0.80

WATER SERVICE AND SEWER RENTS

The following interesting decision is reported by the Municipal Legal Information Service of the New York State Conference of Mayors and Other Municipal Officials:

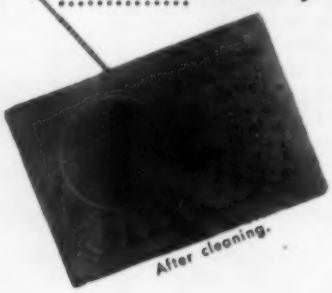
"On October 11, 1940, the Court of Appeals, Richmond county, Ohio, held that the city of Mansfield had authority by ordinance and rules and regulations issued thereunder to shut off water at premises which are delinquent in their sewer rental payments. Pointing out that it is well settled that a city may shut off water for non payment of a delinquent water bill, the Court considers the direct question involved in this case of the power of a city to discontinue one service for failure to pay for another service, and holds that the sewer and water systems are so closely related as to be considered one transaction as the operation of the sewage system is dependent upon the water supply, therefore, it is reasonable to shut off water for nonpayment of a delinquent sewer rental bill. The court cites and relies upon the case of *Dodd v. City of Atlanta*, 113 S. E. 166, which reached the same decision as was reached in the instant case. *Gatton* v. *City of Mansfield*."

Teddy Roosevelt was president when we cleaned Washington's mains in 1907.

1945 — National begins a 5 year job.

Cleaning controlled by 2-way radio.

Before cleaning.



After cleaning.

NATIONAL CLEANING AGAIN

lowers pumping costs

increases volume

increases water pressure

FOR WASHINGTON, D. C.

Way back in 1907 and again in 1926 National successfully cleaned the water mains of Washington, D.C.

In 1945 a five year program to clean and recondition the water main system of Washington was begun and National in conjunction with the Centriline Corporation was successively awarded the cleaning contracts for 1945, 1946, 1947, 1948 and 1949. At the completion of these contracts, National was awarded additional cleaning contracts for 1950, 1951 and 1952—in short, all the cleaning jobs to date.

Tests made on those lines already cleaned and centrilined indicate a co-efficient of over 130 as against less than 90 before cleaning, resulting in lower pumping costs, increased volume and higher pressure.

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Water Main Cleaning and Lining

A review of the technique and advantages of these practices

By J. A. FRANK and A. G. PERKINS

Mr. Frank is Vice-Pres.-Genl. Mgr., National Water Main Cleaning Co., New York, N. Y., and Mr. Perkins is Sales Manager for the Centriline Corp., New York, N. Y.

THIS discussion is designed to explain and illustrate the "why, when, and how" of cleaning and lining water mains. When the carrying capacity of mains decreases, there is a corresponding decrease in the serviceability of the system. Briefly, the need to recover water main capacity is "why" water mains are cleaned.

The curves, Figs. 1 and 2, show the population increase of all the cities in the Southwest Section which reported answers to an AWWA questionnaire, both in 1945 and in 1950. Fig. 1 illustrates trends of cities below 400,000 and Fig. 2 for those of cities above 400,000 population levels.

Examining two sets of curves, we find that there are two cities having negative slopes, indicating loss of population; these two exceptions were caused by military installations which were inactive after World War 2. The conclusion to be drawn from these curves is that, except for distortion caused by war, the population of each city has increased. Consideration of the slopes of these trend curves also indicates that the rate of increase of population becomes increasingly rapid as the population becomes greater.

Increasing Water Consumption

Trend curves for all cities in Figs. 1 and 2 show that the only slopes which are negative are for the cities in which the demand curve is distorted by military installations.

Fig. 4 illustrates the demand for water shown by these cities. The demand, as figured here, is the product of the population times the per capita water consumption. By reexamining Figs. 1 and 2, it will be apparent that the demand is cumulative: as the population increased, the per capita water consumption increased at a faster rate. Thus, the slope of the curves in Fig. 4 is much greater than the slope of the population curves; as pointed out before, the per capita water consumption increases more rapidly as the population increases and, therefore, the slopes on Fig. 4 are a reflection of the cumulative effect of increasing per capita water consumption at the same time the population is increasing.

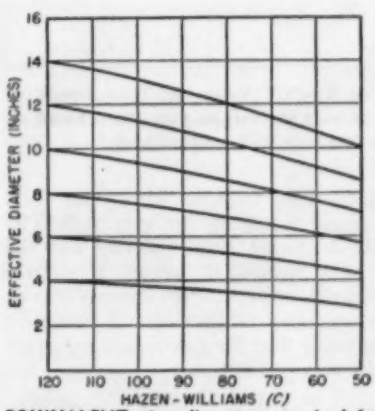
Unaccounted-for Water

Also to be noted is the fact that the slope becomes steeper and steeper as the city grows larger in population. In plotting these data, the unaccounted-for water (the difference between the total quantity produced and the total amount sold) varies; in some cases the amount is as high as 40 per cent. It is interesting to note that, in the cities where the unaccounted-for water is held to 15 per cent or less, each city has had Pitometer surveys made.

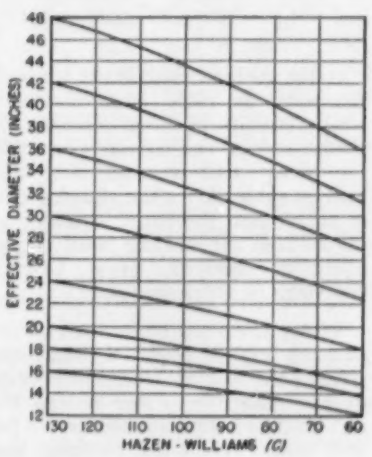
In summing up, we can conclusively see that Fig. 4 indicates the demands on the water distribution systems have become greater and greater. New pipe to take care of this growing demand has not been laid as rapidly as the demand has increased.

The loss of coefficient for the various sizes of pipe as predicted in the Hazen & Williams Handbook is illustrated in Fig. 3. Note that this is a family of curves, and that the centroid of the family has been drawn as a heavier line. The significant point to be noted is that, while the demand on the systems has been going up and up, the coefficients or ability to supply demand has been decreasing at the rates shown.

The equivalent diameters required for pipes as they lose coefficient is



EQUIVALENT pipe diameters required for specific "C" values.



Charts courtesy of Clinton Ingleo, reproduced from Jour. A.W.W.A.

illustrated in the Hazen-Williams "C" valve graphs reproduced herewith. Since the total investment in water mains in the U. S. is estimated at four and one-half billion dollars, a tremendous amount of capital investment is being lost due to loss of coefficient.

Summing up, we find that the load on the water lines is increasing at a very rapid rate, which is cumulative, and that the ability to serve (the capacity of the pipe lines) is dropping at a very alarming rate. Thus, if we can recover the loss of coefficient, and the resultant loss of capacity, we are then in a position to improve and recover this loss in capital plant.

Water Main Cleaning Methods

The process of water main cleaning can be divided into two separate divisions which in the case of smaller pipe, consisting of 4-in. and 6-in. sizes, we will call "drag work." Cleaning of 8-in. and larger diameters is done by the "pressure method."

Drug Method

After preliminary work, such as excavation, notification, etc., the drag work process consists of isolating the main to be cleaned, then making a cut at the entrance point and a cut at the exit point. The nipples cut out of the main usually are 28-in. in length.

A light cable is extended through the water line from one end to the other, either by means of jointed rods or a piston-like device called a carrier. A "make-up," which allows temporary repair at the starting point, and a stuffing box are next installed. The water pressure in the main propels the carrier, which drags the light line through the main behind it. Fig. 5 shows the "make-up" used with fire hose connections.

After the light cable is run through the main, the cable from a power winch, usually ⅜-in. in diameter, is pulled back to the starting point and the "drag" tool is attached to this heavier cable. After the cleaning tool is pulled into the main, entrance to the main at the starting point is permanently repaired, using Dresser couplings or solid sleeves.

Water is turned on so that, as the cleaning tool is pulled through and scrapes the deposit from the interior of the main, the water flushes the dirt ahead of the cleaning tool to the exit hole. When the cleaning tool emerges at the exit point, the line is thoroughly flushed and then is shut down long enough to permit permanent repair at the exit hole. The air is vented from the line and the line is restored to service. It is good practice to shut off the various service connections while cleaning proceeds, in order that the debris will not enter the service lines.

POPULATION GROWTH of cities in Southwest Section of A.W.W.A. (based on 1945 and 1950 data).

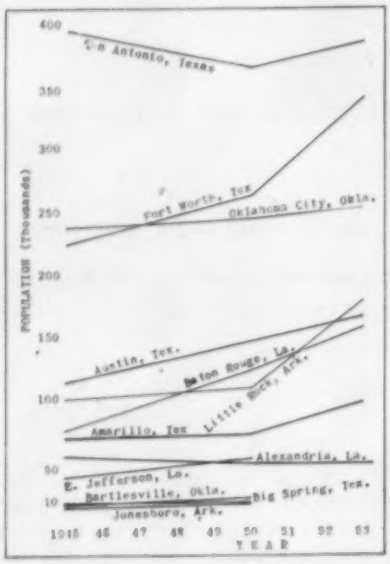


Fig. 1—Cities below 400,000 population levels.

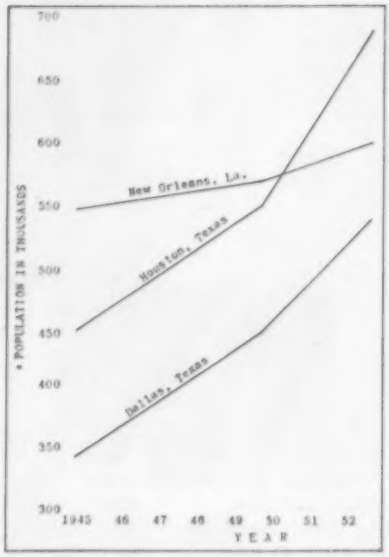


Fig. 2—Cities above 400,000 population levels.

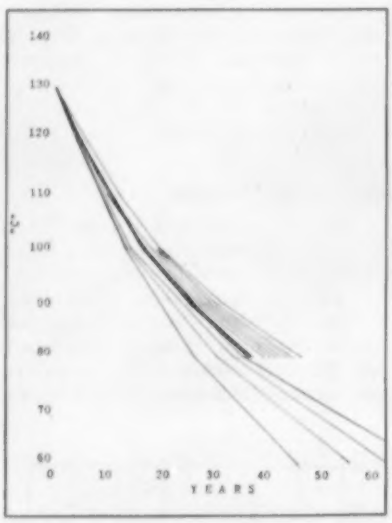


Fig. 3—"C" Value vs. Time Family of curves for various pipe sizes, based on Hazen & Williams Handbook.

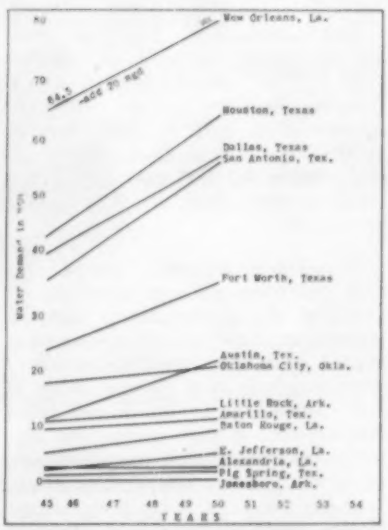


Fig. 4—Water Demand vs. Time Calculated as the product of population multiplied by per capita water consumption.

Pressure Method

The pressure method of cleaning includes the same preliminary steps as the drag method, namely, excavation, notification, and isolating the main. The main is then shut down, and nipples varying in length from 6 feet to 9 feet are cut out both at the entrance and exit holes.

There are two methods of entering the cleaning tool into the main. The first consists of pulling the cleaning tool into the nipple by means of a horizontal tripod braced against the nipple and using a jack, such as a coffing-hoist, to pull the machine into the nipple proper. Fig. 6 shows how

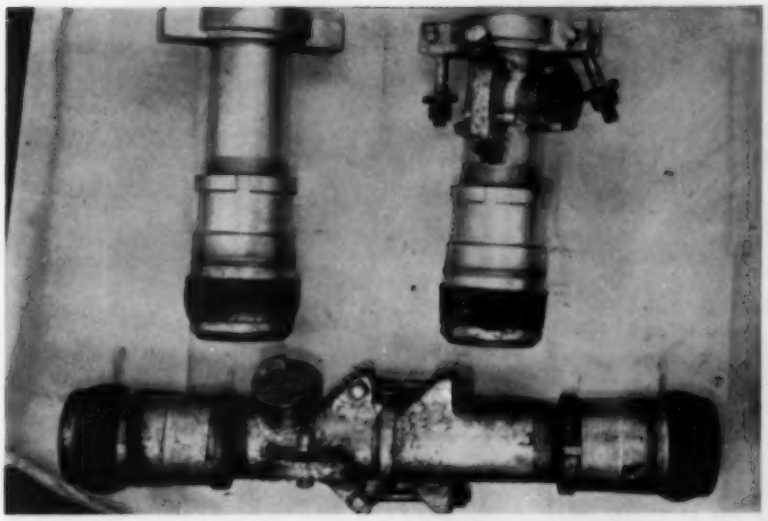


Fig. 5—CONNECTIONS for fire hose are made by these "make-up" devices. Water pressure propels the carrier.

Fig. 6—CLEANING TOOL inserted in nipple by using a jack.

this is done. This nipple, with the machine inside it, is then put back into the main by means of Dresser couplings or solid sleeves.

The water is turned on, and the rate of travel of the cleaning tool is adjusted to between 50 and 100 feet per minute. The cleaning tool, which uses pistons to propel it, has adjustments to permit more or less water to pass through the machine and to flush the dirt ahead of it. When the cleaning tool emerges at the exit point, the line is shut down after flushing. The nipple at the exit point is again recoupled by means of Dresser couplings or solid sleeves.

Cutting the Pipe

In the past, the cutting of the water pipe has always been a time-consuming practice. We are today using multiple cutters so that four cuts may be made simultaneously, thus reducing the length of time the main is out of service.

Fig. 7 shows the set-up using two A. P. Smith cutters which are mounted on the pipe prior to shut-off. These employ specially designed high-cycle electric motors, and are capable of cutting any cast iron pipe in 15 minutes or less. We also use an air-operated saw, and Fig. 8 illustrates two of these saws set up on the pipe. These particular saws have great versatility and are suitable for cutting pipe from 10-in. up to and including 60-in. diameter. These air-powered Wachs saws will cut a cast iron pipe of any thickness in a number of minutes equivalent to the diameter of the pipe. Both cutters illustrated are capable of producing clean, even cuts.

Disposal of Waste Water

In the past it has been difficult at times to properly prepare for disposal of the quantity of wash water resulting when large diameter mains were cleaned in city streets. We have developed a technique, using line caps and small size valves, to hold to a minimum the quantity of water to be disposed of at the exit point. Figs. 9 and 10 show such set-ups on a 24-in. cast iron main. By this means, the total discharge from a 24-in. line, is easily handled by means of two 8-in. discharge lines. Recently we handled the total discharge from the cleaning of an 84-in. steel conduit by using only two 12-in. discharge lines.

Radio for Operations Control

Another modern practice in water main cleaning is the use of two-way radio to control the operation. Two-way radio has been so highly developed and is so successful that we wonder how jobs presently considered routine could have been handled without the use of radio in the past. Positive and instantaneous control of hydraulic grades by two-way radio during the water main cleaning has proven to be advantageous.

The combined use of the line cap and discharge lines with two-way radio control allows the line to be fully charged at all times, and the speed of the machine is regulated by the amount of opening of the discharge valves. One of the hazards, that of the possibility of collapsing the pipe, has been completely obviated; thus, the use of this method of cleaning allows water mains to be cleaned even though the head of water is exceedingly high.

In the past, large diameter machines were awkward and jacking the machine into the main was a time-consuming, laborious process. An 84-in. cleaning tool may now be jacked into a steel main, using our modern, long-stroke hydraulic jack. This operation has been reduced to a matter of minutes, while in the past, hours and sometimes a full day might be consumed in the operation.

Cleaning and Lining Experience

For photographs illustrating the interior of water mains prior to cleaning, and after cleaning, see *Water & Sewage Works* Reference and Data Edition, May, 1954, pages R-23 to R-32. The quantity of material removed from 7,000 feet of 24-in. cast iron main recently on a job at Lynbrook, Long Island, N. Y., is illustrated in Fig. 11.

Where there has been deterioration of the original pipe, serious consideration must be given to rehabilitation by means of a cement-mortar pipe lining, which not only will preserve the coefficient of carrying capacity, but will stop leaks. This consideration applies to graphitic corrosion in cast iron mains as well as to the deterioration of steel mains.

It has been very general experience that, unless corrective chemical treatment is instituted, a pipeline coeffi-

TESTED AND RECORDED

Will the pipe you buy today withstand the increasing punishment of the heavier, higher speed traffic of tomorrow? Cast iron has been tested and has a record of 100 years service in over sixty larger cities in the United States.

Routine load bearing tests as illustrated assure the purchaser of trouble free service from APCO Cast Iron Super DeLavaud Pipe.

In sizes 3" to 24" in modern long lengths. Bell and Spigot, Mechanical Joint, Flanged and Roll-on Joint pipe.

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Sliding or screw type cast iron valve boxes for covering 4" through 10" valves for water or gas. Rugged construction for lifetime service. 5¼" shaft. Extensions as required.

Adjustable VALVE BOXES

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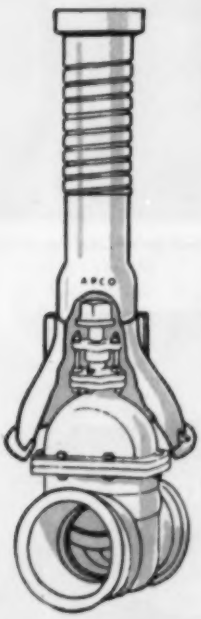

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Valve boxes supplied with separate bases are available in sliding or screw type. Made with 5¼" and 7" shafts with extensions as required. Also, a complete line of service and roadway Boxes.

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cient will be reduced more rapidly after cleaning than its previous rate of reduction. This is unquestionably caused by inability to do a good job of cleaning without seriously damaging the already penetrated original interior protective coating.

Cement Mortar as Protective Lining

The use of cement mortar as a protective lining for water pipelines has a history of over 100 years. As early as 1836, a report of the French Academy of Science recognized the use of cement mortar linings prior to that date. The history of cement lining in the U. S. began before 1850, when cement lined and coated sheet metal pipes were first used in carrying aggressive waters by Atlantic Coast cities.

Some of these early pipelines are still in service. Harold Ohland, Division Engineer of the Jersey City, N. J., water system, has reported on an 8-in., light-gauge metal pipe, having an interior and exterior covering of cement mortar, which was put in service some time prior to 1885, the year of his oldest record of the line. That pipeline is still in service today, and there is no immediate plan for retiring it.

Figs. 12 and 13 illustrate a 16-in. pipeline removed from service in Jersey City in June, 1947; the pipe was laid in 1858. It consists of approximately 14-gauge wrought iron sheet, riveted as shown. The inside was protected by a layer of cement mortar lining about ½-in. thick. This pipe was free of tuberculation or corrosion, and the shell was water-tight after 89 years of use carrying an aggressive water.

The success of cement mortar to protect metal pipe from corrosion has been discussed in many published articles. James E. Gibson, Manager, Water Dept., Charleston, S. C., and Harry Y. Carson, Research Engineer, American Cast Iron Pipe Co., were particularly interested in the early 1920's in a lining for cast iron pipe which would withstand the very aggressive water of Charleston. Their studies of the behavior of cement mortar in pipelines (which at that time had been in use for over seventy years) led to the installation, by the City of Charleston, of the first known cast iron pipe having factory-applied spun cement mortar lining. This type of cement lining for new cast iron pipe is now common in modern practice.

While experience has demonstrated that pipes properly cement lined at the factory would not corrode or tuberculate on the inside, many pipelines are installed to carry aggressive waters without cement mortar protection. Once the original paint, tar,

CUTTING PIPE. (Left) Fig. 7—High-cycle electric motor A. P. Smith units. (Right) Fig. 8—Air-operated Wachs saws will cut all C. I. Pipes.

WASH WATER DISPOSAL. Figs. 9 and 10—Line caps and small size valves enable two 8-in. lines to handle discharge from 24-in. main.

DEBRIS REMOVED. Fig. 11—This quantity of material resulted from cleaning 7,000 feet of 24-in. main at Lynbrook, N. Y.

or asphalt coating applied to new pipe at the factory has been penetrated, water comes in contact with the metal and tuberculation starts. The effect of tuberculation on carrying capacity during times of rising demands, and the resulting need for main cleaning, have been described.

Experience with Aggressive Water

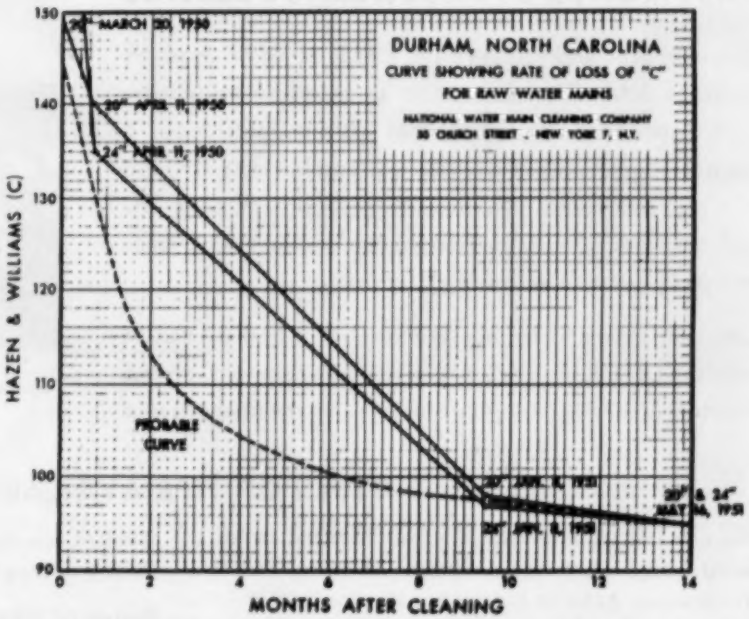
The need for protective treatment in addition to cleaning is evidenced by the fact that pipelines re-tuberculate after cleaning. In fact, re-tuberculation develops more rapidly after cleaning than before. Fig. 14 illustrates the loss of coefficient in water pipelines after cleaning. These data represent about ten years of experience in Durham, N. C.

It should be noted in Fig. 23 that the two lines, hydraulically parallel, show about the same characteristics in loss of coefficient. By 1951, nine months after cleaning, both pipelines had lost about 40 points on the Hazen and Williams scale. This program of cleaning, started in 1940, had made it necessary by 1950 to re-clean every year. The cleaning was timed for late spring so that maximum delivery of both pipelines was available for the summer peak load.

Another example of the effect of extremely aggressive water is in Charleston, S. C. Mr. Gibson stated, in a report published in the New England Water Works Journal in 1926: "The Charleston Water Department had experienced for years a material falling-off in the carrying capacity of the cast-iron mains throughout its distribution system. This was particularly called to their attention in the constantly increasing friction head of their twelve miles of 24-in. cast-iron main between their pumping station and the center of distribution. This main had been cleaned three times, with the result that after each cleaning the friction losses increased very much more rapidly, and in the last cleaning 80 per cent of the results from cleaning had been overcome within 30 days after cleaning. That is to say, the coefficient after cleaning had been restored to practically that of new cast-iron pipe, but within 30 days after the date of cleaning this coefficient had again decreased until it was practically the same as that before cleaning."

The Durham and Charleston examples are chosen as the extreme in re-tuberculation, and are not typical of less aggressive waters.

90-YEAR OLD PIPE. (Left) Fig. 12—Jersey City's 16-inch, riveted wrought iron line. (Right) Fig. 13—inside protection by cement lining.



RE-TUBERCULATION. Fig. 14—Experience shows pipelines tuberculate more rapidly after cleaning than before they are cleaned.

Cement Lining Pipelines in Place

Until 1933 there was no satisfactory method for placing a cement lining in large pipelines already installed. During that year a process for cement lining pipelines in place was invented and developed by Albert G. Perkins. This process had its first field trial on a short section of an installed 72-in. line in Jersey City, N. J. The process is known today as the Centriline process of centrifugally applying cement mortar.

The test at Jersey City received little publicity, but its success led to the cleaning and lining of over 27,000 feet of old 48-in. riveted steel line supplying Newark, N. J., from Macapin intake. The cement lining of this pipeline not only restored capacity lost through tuberculation, but exceeded by 14 points on the Hazen and Williams scale the original clean pipe capacity. The improved capacity resulted from the streamlining of surface over the large rivets on the inside of the pipe. In addition, the lining stopped all leakage through holes in the pipe wall caused by interior or exterior corrosion.

Because of an intense need for a method of cement lining pipes in

Installing 10" U. S. centrifugally cast iron pipe for a water distribution system

CAST IRON PIPE FOR WATER SERVICE

The practice of using cast iron pipe for water service started in Europe around 1455 and around 1820 in this country. This practice has continued down through the years and it is still the most widely used type of pipe for water distribution systems. The most desirable combination of strength and long life has made and still makes the use of cast iron pipe the most economical in the long run. Our strategically located foundries are well equipped to furnish cast iron pipe and fittings in sizes starting at 2-inch for intakes, pump stations, filtration plants, supply, feeder and distribution mains.

CAST IRON PIPE FOR SEWERAGE SERVICE

Cast iron pipe and fittings have a wide application in the sewerage field. They have three outstanding properties: 1. tight pressure type joints that prevent infiltration, 2. beam strength, compressive strength and bursting strength to withstand severe installation conditions, 3. long life and resultant low amortization charges that have been proven by years of satisfactory service.

Cast iron pipe and fittings in sizes 2-inch and up can be furnished for flow lines, pressure mains, siphons, stream crossings, outfalls, pumping stations and treatment plants.

Section of 36" cast iron outfall sewer installed on concrete piers

TYPES OF PIPE AVAILABLE

Our cast iron pipe centrifugally cast in metal molds is manufactured in accordance with American Standard Specifications A21.6 or Federal Specification WW-P-421a. Pit-cast pipe is made to conform to American Standard Specifications A21.2.

Fittings (bell-and-spigot) can be furnished in accordance with American Standard Specifications A21.10 for the short-body type 3-inch to 12-inch, also A.W.W.A. Specifications C100 3-inch to 60-inch for the long-body type.

Fittings (flanged) are made to conform to American Standard Specifications Class 125 (B16.1) and Class 250 (B16b) or long-body A.W.W.A. type.

Mechanical joint for cast iron pipe and fittings is made in accordance with American Standard Specifications A21.11. Pipe and fittings can be furnished with cement lining in accordance with American Standard Specifications A21.4 or manufacturer's standard.

Flexible joint pipe, flanged pipe and plain end pipe are made to standard or manufacturer's specifications, whichever are applicable.

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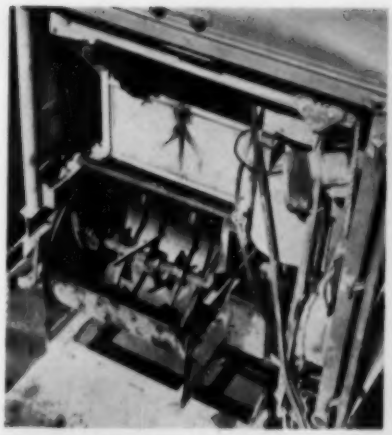
place, this first contract aroused much interest in the waterworks field. Papers by Banks and Inglee were published and an editorial by William W. Brush described the "making of the Newark line better than before" as "a noteworthy achievement in the water works field."

The success of the first 48-in. job led to the development of machines and equipment for the lining of smaller diameter pipe. The first step was to line 36-in., then 30-in., and then 24-in. diameter pipe. It was believed for some time that 24-in. was the smallest diameter pipe which could be lined by a proportionate reduction of the original lining machine, since it is considered the smallest size pipe in which a man of normal size can enter the pipe, turn around, and leave the pipe.



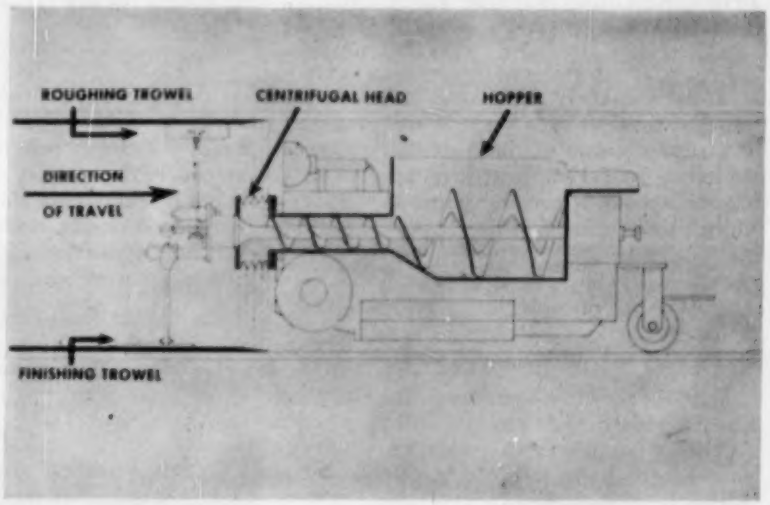
LINING EQUIPMENT. (Left) Fig. 15—Electrically driven mortar mixer. (Right) Fig. 16—Travel buggy carries mortar through pipe to lining unit.

Field Equipment for Lining

In this size range, a typical field setup would include a trailer stationed at the entrance of the excavation. It provides an electrical generator which supplies power to all of the lining units and support equipment. Mortar for lining is mixed in an electrically driven, specially designed mortar mixer mounted in the rear of the trailer, Fig. 15. Special attention is given to the slump of the mortar. The capacity of the mixer is such that ample mixing time is assured.

Mortar ordinarily is discharged directly into a chute which carries it down to a "travel buggy," Fig. 16. Trailing an electrical supply cable, the "travel buggy" carries a supply of mortar through the pipe for a distance of approximately 1000 feet to the lining unit. The lining unit starts operation at the maximum operating distance from the supply excavation and works toward it.

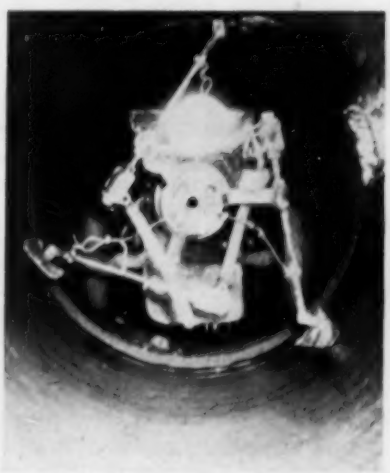
A "mortar supply buggy" which travels with the lining machine receives the full charge of mortar from the "travel buggy" and feeds the mortar continuously into the lining machine hopper while the travel buggy goes back for another load. In the hopper, the mortar is carried by a screw type conveyor through a tube into the center of the applicator, Fig. 17. At this point, a device extrudes the mortar evenly in all directions through slots in the tube—forcing it directly into the base of the blades in the rotating applicator.



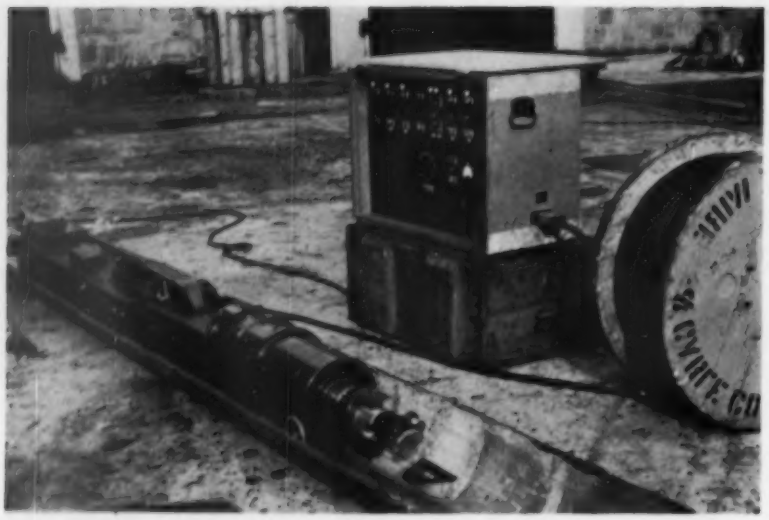
LINING APPLICATION. Fig. 17—Within the water main, mortar is extruded and then trowelled to walls of pipeline.

The Centrifugal Applicator

The centrifugal applicator rotates



INTERIOR LINING. (Left) Fig. 18—Machine started at this end. (Right) Fig. 19—Trowel end of 30-in. lining machine in action.



AUTOMATIC LINING MACHINE. Fig. 20—Remote control operates this unit designed to fit pipe diameter of 16-in. size.

at approximately 1000 rpm and throws the mortar onto the pipe wall in a steady stream of fine particles. Projecting behind the centrifugal applicator is a slowly rotating frame on which two or three finishing trowels are mounted. The trowels are held against the freshly placed mortar by a light spring pressure, in order to flexibly align the trowel and to produce a very smooth lining surface.

Fig. 18 shows where the lining machine started operation in a 36-in. cast iron pipe, and reveals the unlined portion at the edge; beyond the cement mortar may be seen as it was projected before trowelling; and farther back, the troweled section as the trowels were released onto the mortar surface. A lining machine in operation inside a 30-in. pipe is illustrated in Fig. 19.

Lining thickness is changed by varying the travel speed of the machine. Thickness of the lining depends on the size and condition of the pipeline. Most cement linings are from 3/16 to 3/8 inches in thickness.

Automatic Lining Machine

All machines to line 24-in. and larger sizes of pipe were designed to be accompanied through the pipeline by an operator. Since it was originally considered impractical for a man to work in pipelines smaller than 24-in. in diameter, Centriline in 1950 built a machine which could be operated entirely by remote control. This machine was designed to operate in pipe diamters as small as 16 inches, Fig. 20. The new unit is sometimes referred to as the automatic lining machine, since the various operations are automatically coordinated or are electrically or mechanically interlocked to control proper sequence of operation.

The cement mortar is pumped through a flexible hose to the automatic unit at a rate which is automatically coordinated with the demand of the machine. The hose through which the mortar is forced is automatically retracted ahead of the machine by a winch located on the surface of the ground. All functions of the machine can be controlled from a switchboard on the surface, Fig. 20. The basic principle of applying the mortar is the same as in the larger machines.

In spite of original doubt that it was feasible for men to enter 16-in. pipe, all 16-in. and larger pipes lined are now inspected before and after lining by men traveling through the pipe on wheeled carriages.

In the centrifugal method of lining pipes, the pipeline fittings such as valves, tees, and corporation cocks offer no problem—only the amount of mortar to produce the required thickness of lining is projected from the center of the pipe by the applicator. Any special fittings are easily shielded or plugged prior to the passage of the lining machine. After the lining has been placed and has taken its initial set, a man enters the pipe to remove plugs and to execute any minor hand work which might be necessary at special pipeline fittings.

Additional Methods of Lining Pipe

Two other methods for applying cement lining in large pipelines have been used in the United States since the development of the centrifugal process. One method utilized compressed air to blow cement, sand, asbestos and water onto the wall of the pipe in a manner similar to a slowly rotating cement gun. The second method utilizes compressed air to blow premixed mortar through slowly rotating tubes to the wall of the pipe.

The Tate Lining Process

A method of placing a cement lining in small diameter pipelines was invented by William T. Tate of Sydney, Australia. This method has been used in the United States since 1937 for lining pipes from 4 to 14-in. in diameter.

The Tate process utilizes a bullet-shaped tapered lining tool to press the cement mortar on the side of the pipe. Excavations for lining are made at approximately 300-foot intervals. The pipe is cleaned by conventional methods using a cable-drawn or hydraulic cleaning tool. Cleanings of debris and water are removed by rubber discs drawn through the pipe, Fig. 21.

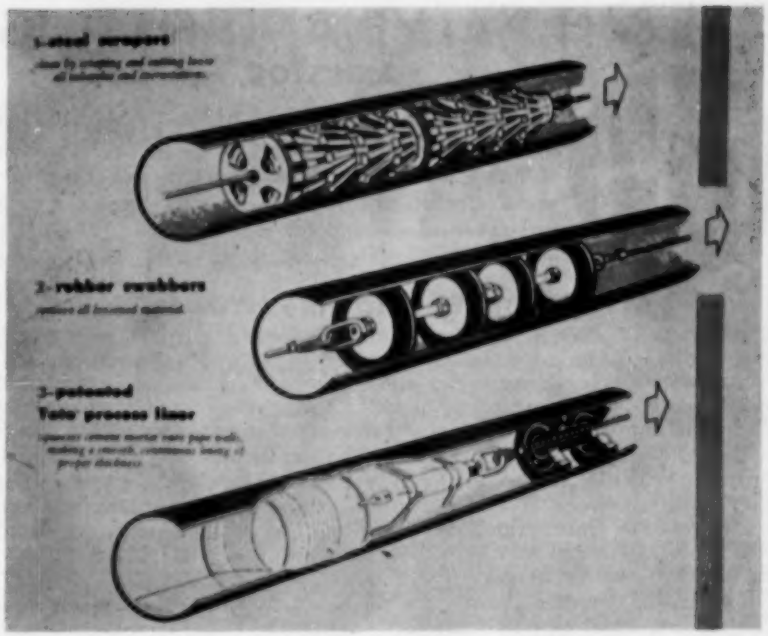
With a cable threaded through the section of pipeline being cleaned, sufficient mortar to line the entire section is forced into one end of the pipe. The cable is fastened to the lining tool, and the tool then is drawn slowly through the pipe section by means of a winch located at the opposite end of the pipe section.

The lining tool, Fig. 23 consists of a hollow bullet-shaped mandrel which tapers up to a maximum diameter about ½-in. less than the inside diameter of the pipe to be lined. Guide springs hold the mandrel centered in the pipe so that there is about ¼-in. clearance between the trailing edge of the lining tool "skirt" and the pipe wall. The "skirt" is perforated by several rings of closely spaced small holes.

As the lining tool is drawn through the pipe, the mortar pushed ahead of it creates a back pressure which keeps the space between the lining tool and the wall of the pipe filled with mortar. Since the skirt on the lining tool is tapered, the mortar is firmly pressed against the wall of the pipe. The re-

sulting pressure forces water and some cement through the small holes in the skirt, leaving firm and smooth mortar around the wall of the pipe and a "flat" in the bottom consisting of excess cement squeezed out of the lining.

Special fittings, corporation cocks and valves are excavated and temporarily removed when lining with the Tate process. The winches which pull the various tools through the pipe are located at opposite ends of each section.



CLEANING AND LINING. Fig 21—Above are scrapers and swabbers for cleaning; and below, Tate process lining tool.

Cement and Sand Specifications

Cement and sand are carefully chosen for this type of work. The sand must be clean, sharp silica sand, and must meet certain grading standards.

Cement ordinarily used is Portland Type II. This often is blended with natural cement, or with high grade pozzalanic material. The ratio used is five parts Portland Type II to one part natural cement or pozzalanic material. The ratio of sand to cement varies from 1.0 to 1.5 parts of sand to 1.0 part of cement.

LINING TOOL. Fig. 22—The hollow bullet-shaped mandrel, centered by guide springs to give ¼ in. clearance at "skirt" end.

Advantages of Mortar Lining

There are important reasons for the adaptability of cement mortar to the lining of pipelines in place.

(1) The normal moisture inside a buried pipeline provides a condition to which cement is best suited. Cement mortar lining develops its highest strength when kept saturated with water.

(2) Pipe surfaces cleaned by conventional methods retain particles of the original coating and the corrosion products. Under these circumstances, complete dependence cannot be placed only on a bond between the lining and the pipe surface to hold the lining in place. Cement mortar has the high compressive strength necessary to hold itself in position as an arched ring on the inside of the pipe.

(3) Steel pipelines in many instances have been pitted through because of outside or inside corrosion on local areas. Cement mortar has the strength necessary to bridge these holes and to prevent leakage, even when the pipe is carrying water at high pressures.

(4) The chemically alkaline nature of cement mortar is an important factor. No thin lining material can be expected to completely isolate the inside surface of a long length of pipeline from corrosive water throughout long years of service. The pH value of moisture which penetrates a cement mortar lining is increased to a level which is non-corrosive to ferrous metals. To maintain this condition the mortar must remain continually saturated (as is the case in water pipelines). The "zone of alkalinity" created at the surface of the pipe wall prevents tuberculation and corrosion.

(5) The adaptability of cement mortar to forming a very smooth surface which will provide high pipeline carrying capacities.

M & H VALVE AND FITTINGS COMPANY

ANNISTON, ALABAMA

The letters M & H are the sign of quality on Valves, Hydrants and Pipe Line accessories. High quality materials, simplicity of design and expert workmanship have established for M & H enviable reputation for dependable service in the water works and sewage fields and for industrial uses. M & H products are modern in design, with many exclusive M & H features.

Traffic Model Hydrant

Right: Standard Model Hydrant

Gate Valve

M & H VALVES AND FIRE HYDRANTS

M & H A.W.W.A. Gate Valves are furnished double disc parallel seat, or solid wedge, iron body, bronze mounted, non-rising stem, or outside screw and yoke. Available spur or bevel geared and with enclosed grease case, also hydraulically or electrically operated. Sizes 2" to 36". Low Pressure and High Pressure Valves and Square Bottom Valves are an established part of the M & H line.

M & H Compression Type Hydrants conform to latest specifications of the American Water Works Association. They are available either in standard, flush type or traffic models. Hydrants with 5¼" and 6¼" valve opening are listed and approved by Underwriters Laboratories of Chicago and Associated Factory Mutuals of Boston and A.W.W.A. Hydrants with 4¼" and 4½" valve opening are A.W.W.A. approved only.

Outstanding features include dry top, easy to lubricate, revolving head. Can be lengthened and working parts completely removed without digging up hydrant.

FILTER PLANTS & SEWAGE PLANTS

Hydraulically and electrically operated M & H Valves are used in sewage treatment plants, water works, filter plants, etc., to save time and labor since these valves can be operated by remote control for quick, easy closing or opening. They are also used as emergency valves to admit higher water pressures into the mains in case of fire. Sizes 2" to 36" A.W.W.A.

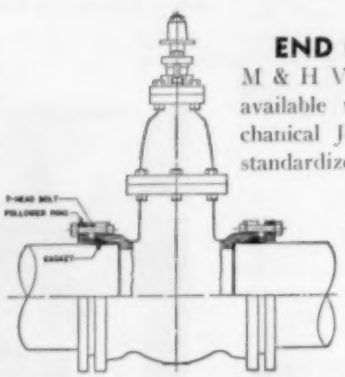
Hydraulic Gate Valve

Low Pressure Gate Valve Rising Stem

M & H Flap Valves and Shear Gates are iron body, bronze mounted, used in Filtration and Sewage Disposal Plants.

Low Pressure Gate Valve Non-Rising Stem

Shear Gate



END CONNECTIONS

M & H Valves and Hydrants are available with Standardized Mechanical Joint ends for use with standardized mechanical joint cast iron pipe, also with hub ends, flanged, Ring-Tite and Universal ends.

FIRE PROTECTION

M & H makes a complete line of valves, hydrants, indicator posts and underground pipe fittings for fire protection water systems. All of these M & H products are approved and listed by the National Board of Fire Underwriters of Chicago and by the Associated Factory Mutuals of Boston. All castings therefore are marked "UA—FM."

Rising Stem Gate Valve

Spring Check Valve

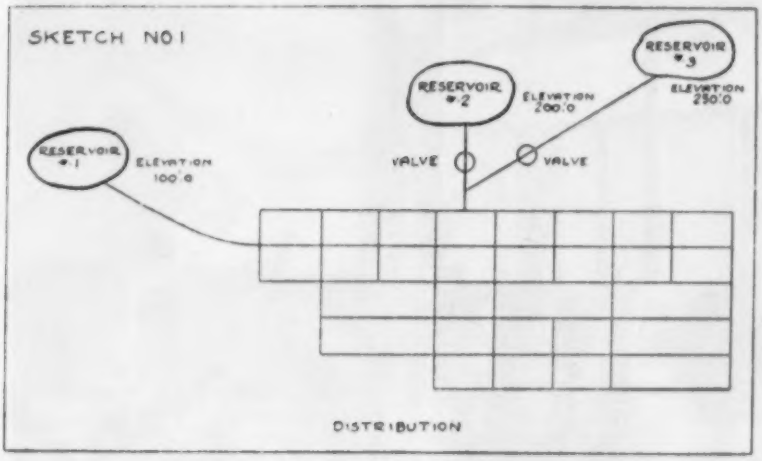
Indicator Post

M & H PRODUCTS INCLUDE:

WALL CASTINGS	FLANGED FITTINGS	TAPPING SLEEVES AND VALVES
CHECK VALVES	FLOOR STANDS	SPRING LEVER CHECK VALVES
EXTENSION STEMS	SHEAR GATES	MUD VALVES
FLAP VALVES	S & S FITTINGS	FLANGE AND FLARE FITTINGS
	CUTTING-IN TEES	

Application of Altitude Valves and Pressure Regulators

By WILLIAM F. END
Engineer and Treasurer, Ross Valve Mfg. Co.
Troy, N. Y.



Valves to Balance Head

THE SUBJECT matter of this paper is a review of the practical and successful installation and operation of automatic valves — some having been in service (and on 24-hour duty) for a half century.

Along with the development of the science of supplying pure water, has grown the closely allied work of distributing this water to the population being served. As the areas of population have expanded with the evolution of running water at the tap in the household, and the extinction of the public well, so likewise have the problems of pressures and pressure control expanded.

The old adage, "You never miss the water till the well runs dry" was never more true when applied to the present-day water supply. From the standpoint of health, and the danger of fire hazard to a community, even a temporary shut-down of service or pressures in a public water supply is of serious consequence.

The magnitude and responsibilities of the present-day water supply system have necessarily caused water works engineers and operators to turn to the use of automatic devices for increasing the efficiency and reliability of the service. Let there be no mistake about the responsibility of these individuals; theirs is a 24-hour job subject to the mandates of the commission, politicians, and individual consumer. To provide anything but a miserable existence for the operator, it becomes a "must" to have in the system devices such as automatic valves and automatic equipment.

The advantages of an automatic pressure control valve, properly designed, installed and maintained, permit flexibility within the system because of the ability of this device to adjust itself for the normal and abnormal conditions over the 24-hour day; and without undue attention by the operator.

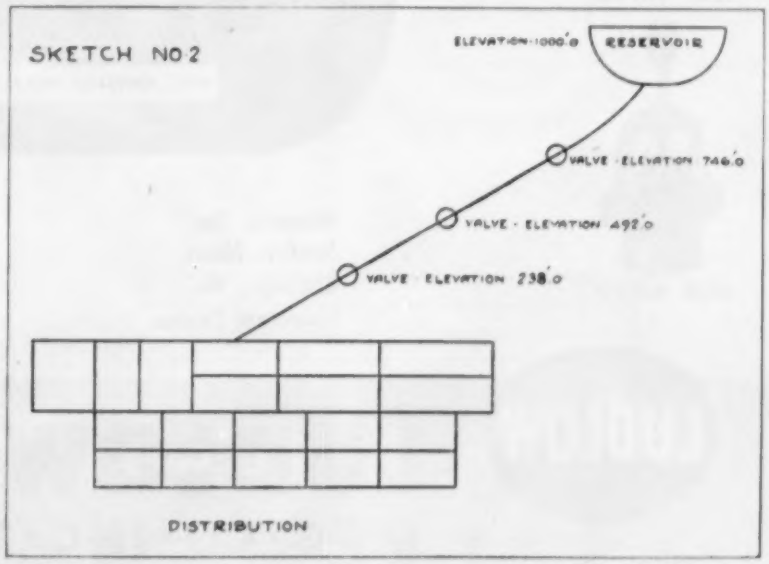
Types of Automatic Valves

There are four standard types of automatic valves, any one or combination (a single unit having two or more controls) of which may serve in the control of flow or pressures—thereby increasing the efficiency of the complete water supply system. A gravity or pump supply with or without tanks floating on the system undoubtedly will have need for some type of automatic valve which will correct unbalanced or excessively high pressures.

The four basic or standard types of automatic valves may be identified as: 1. Pressure Reducing, 2. Altitude, 3. Relief-Surge-Back Pressure, and 4. Float.

Pressure Reducing Valves

The first of these valves made its appearance in the waterworks field as a throttling orifice in London about 1700. Constant pressure reduction was, of course, possible only with a uniform rate of flow. The engineer



Valves to Reduce Static Pressure

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SLUICE GATES

SHEAR GATES

FLAP VALVES

MUD VALVES

STILL ANOTHER INSTALLATION WITH LUDLOW VALVES

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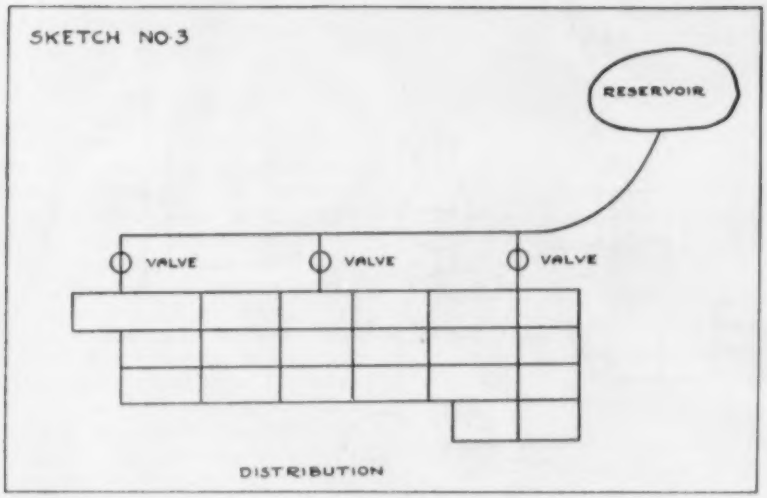


Valves to Balance Unequal Pressure

soon devised a means of changing automatically the size of orifice (in smaller valves only). This device was in the form of stem movement into and out of the valve seat. While the change was an improvement, the design made use of an unbalanced stem and was considered by qualified students to be bad practice.

As late as the 1870's, presure reduction in water supply for pipe lines larger than 3" was accomplished by what was known as *break-point basins*. Water discharging from a pipe into these small basins would reenter the pipe at about zero pressure; and, depending on the head or pressure to be dissipated, one or more break-points were a part of the gravity pipe line from reservoir to distribution. By this method of pressure reduction, control for the varying rates of flow was difficult and resulted on the one hand in overflow of the basin with consequent waste of water; and, on the other hand, drainage of the basis and entrained air in the pipe line. The engineer's problem of maintaining adequate flow, pressure reduction and elimination of air and waste was ultimately solved by replacement of break-point basins with the pressure reducing valve.

A valve which will maintain constant pressure at its discharge side is considered a *pressure reducing valve*. In the sketches immediately following are illustrations of the use of this valve adapted for the particular need in conduit from reservoir to distribution.

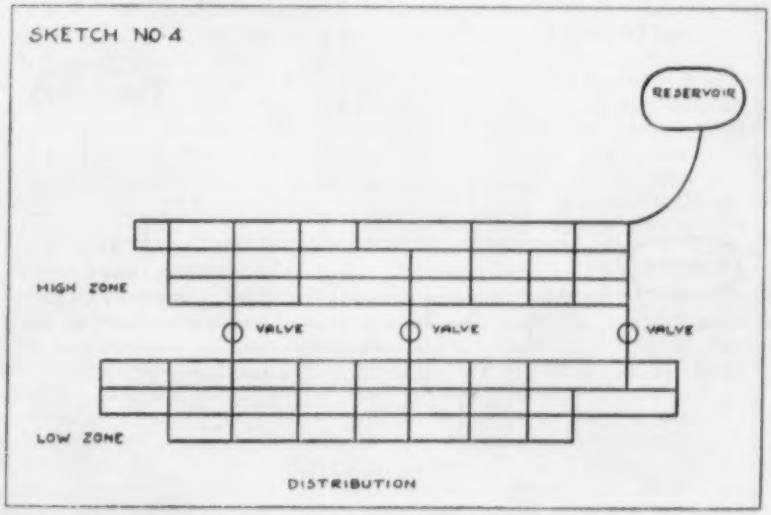
Sketch No. 1 shows reservoirs and a distribution system in which, as the extensions enlarged the system, additional reservoir or storage is required. Since reservoirs normally cannot be located at one elevation, the problem of heads becomes one of the balancing of pressures; and the need, therefore, of automatic devices. Pressure reducing valves in the pipe lines from the reservoirs of higher elevation may be adjusted to discharge into the system at the same head as that available from the low reservoir.

Sketch No. 2 is another illustration showing the need of pressure reduction in a pipe from a reservoir having an elevation (let us assume) 1000 ft above the distribution system. If the satic pressure of 1000 ft (or approximately 435 lbs) were to enter distribution, with no stretch of imagination one may visualize the problems with which the operator would be confronted. Three stations of pressure reduction from 110 lbs to 10 lbs each would dissipate approximately 700 ft or 300 lbs of static head; and allow approximately 100 lbs pressure to safely enter the distribution.

Sketch No. 3. Where, because of the contour of the terrain, a community is inflicted with a distribution which has much greater length than breadth, and a supply entering at one end, the problem of unequal pressures because of head loss is a major one. Assuming the trunk main runs the length of the distribution system, uniform pressure may be had throughout the entire length of the system by supplying water through pressure reduction chambers located at strategic points along the feeder main.

Sketch No. 4. A community located on a side hill, with little or no flat land, presents a problem of pressure zoning; and suggests inter-connection of these zones by pressure reducing valves. When our forefathers chose to settle on the banks of a river in mountainous and semi-mountainous country, they had in mind water transportation and water supply in the form of the hand pump and bucket. Expansion and development was adjacent to the river; however, when expansion (prompted by the river flooding low lands or for other reasons) started movement up hill to higher ground, the settlers promptly engineered the first of our gravity supplies. As the community or city grew upon a side hill, so also grew the problem of constant and uniform pressures, resulting in the development of pressure zoning and the further need of the pressure reducing valve.

Sketch No. 5. In passing, comment should be made on the so-called "sleeping valve." This valve (pressure reducing) located between two systems, zones or districts, opens occasionally only for a pre-adjusted pres-



Valves to Zone Pressure

sure to supply makeup water for the zone on the discharge side of the valve. The valve also may be made to allow a reverse flow if there is need for such provision.

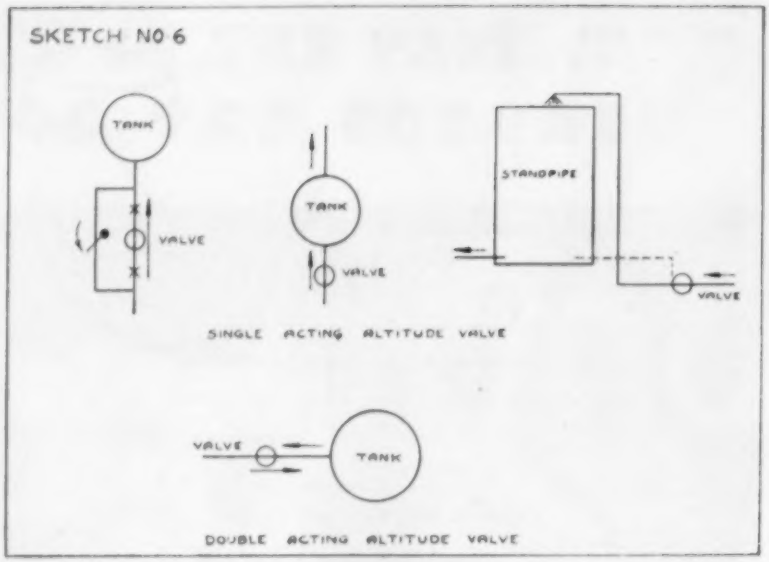
Altitude Valves

The altitude valve, another of the four standard automatic valves, attracted attention and interest when standpipes and elevated tanks were accepted by the waterworks profession as efficient instruments in the operation of the distribution system. The valve increased the value of the tank by effectively controlling the water storage.

Filling a tank on the off-peak load and automatically isolating the tank for use during peak loads is the service which altitude valves contribute to the efficient performance of the tank and, consequently, to the overall efficiency of the system. The use of this valve is not confined to tanks alone, for they are used on open and closed reservoirs in filtration plants, and in aerator basins.

In specifying an altitude valve, one usually calls for a single or double acting valve, amplifying in the specifications a particular feature — depending on the service requirements. If an assembly so specified does not make of the valve a combination valve (an assembly to be treated in subsequent remarks) the valve is classified as a single or double acting altitude valve.

Sketch No. 6. A single acting altitude valve is one which permits flow into the tank or reservoir and closes to prevent overflow. Discharge from tank or reservoir is taken through a separate pipe or a bypass and swing check around the altitude valve.



Single and Double Altitude Valves

A single acting valve may have an external control which will allow the stem in the main valve to operate in two positions—wide open and closed —or as a throttling valve where the main stem floats on the column of water, gradually closing as the water rises in the tank or reservoir.

The double acting valve opens wide to pass water into the tank, closes to prevent overflow, and opens wide for reverse flow from tank to distribution. The installation of this valve would therefore require but a single pipe for supply to and discharge from the tank.

The location of an altitude valve should be adjacent to the tank or reservoir, or as near as construction obstacles will allow. Such location will permit communication to the pilot of the true static head of water in the tank, which otherwise is not possible because of friction loss between valve and tank. A true static pressure communication to pilot will guarantee sensitive and accurate control of the tank.

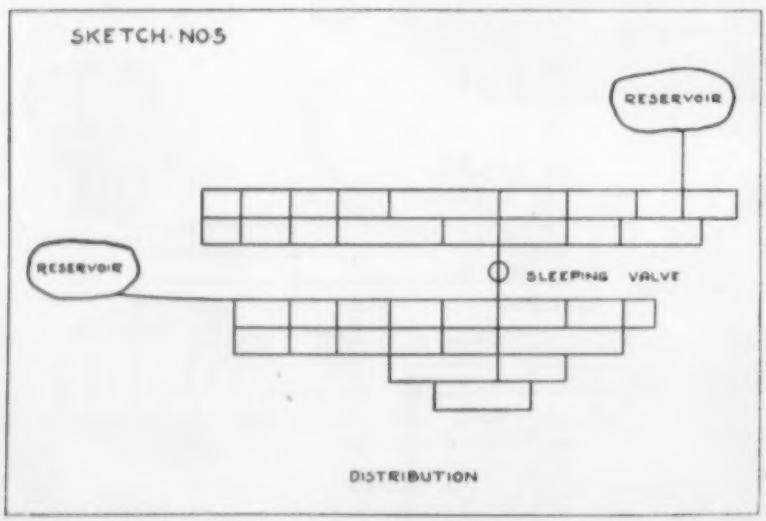
Altitude valves are normally controlled by hydraulic pilots; however, both the single acting and double acting altitude valves may be controlled by a three-port solenoid which is actuated (energized or de-energized) by a float or pressure switch.

Relief or Surge Valves

The relief or surge valve, sometimes called back pressure valve, is another of the four standard types of automatic valves in use in the waterworks field. This valve responds to pressures at its inlet side rather than to pressures at the discharge side, as is the case of the pressure reduction valve or the single acting altitude valve.

When referred to as a relief valve, it is considered an automatic device for releasing a gradual pressure rise which may, without correction, subject a pipeline to a rupturing pressure. The installation is made where there is easy disposal of the wasted water necessary to dissipate the pressure wave or back-flow surge within the line. The location of the valve may be in a side outlet discharging to a stream, well, or zone of lower pressures.

In terms of a surge valve, we think of the valve as an automatic device which will arrest sudden pressure rise —the intensity of which may produce hammer in the pipeline. Installation



Valves to Supply Make-Up Water

may be as mentioned above or, where used in conjunction with pumps, in a bypass around swing check and pump to the suction.

As a back pressure valve, we think of an installation where the upstream pressure (not to exceed a predetermined amount) is to be maintained. When performing as a back pressure valve, the valve passes or discharges only that volume of water which will hold the upstream pressure of that desired. This type of service is advantageous in a system of two zones where one (during certain periods of the day) may waste a volume above its requirements to another. The valve will pass only the amount of water limited by the adjustment of the pilot so that the zone receiving this water cannot receive an overdraft through the valve.

A valve of this description (in addition to the use just described) may serve as a protective measure against over-drafting by deep well pump. Also, installed in a service reservoir receiving water from a storage reservoir, the valve may be adjusted to throttle flow; and, at the same time, maintain pressure on aerator nozzles for aeration.

Float Valves

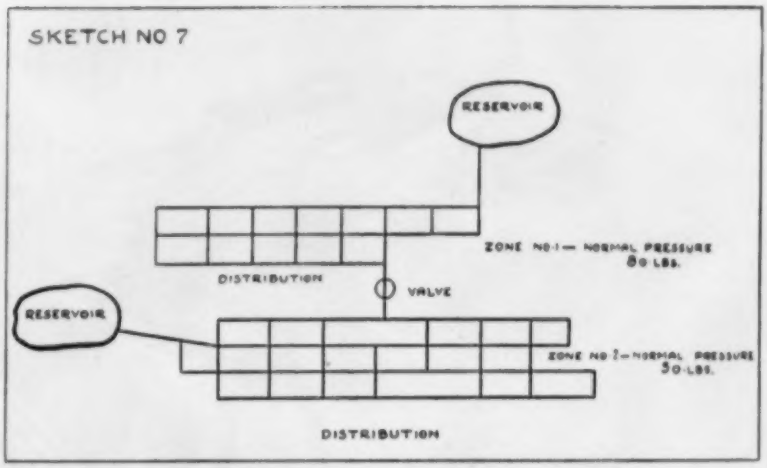
Another of the standard automatic valves is the float valve. This assembly may be specified as direct acting (with float and lever arrangement) or with main valve stem supported by large float (hydraulic pilot operated or solenoid pilot operated). In any case, a float is the prime mover and is directly or indirectly responsible for movement of the stem in main valve.

As a direct acting valve, the operation is throttling; however, as hydraulic pilot controlled valve, its operation may be throttling or the stem may be made to assume a wide open or closed position. When a solenoid pilot is used in conjunction with a float switch to actuate in the main valve, the stem operates in either a wide open or closed position.

In the waterworks field, the float valve is used extensively in warm climates where freezing will not interfere with the movement of the float; however, in colder climates where the use of the valve is a problem (due to its exposed mechanism) the operator may substitute some form of altitude valve.

Combination Valves

At this point, having covered the four standard assemblies of automatic valves, it would be an oversight if we failed to comment on the combination valve. These have only in recent years been recognized as a further step toward more efficient control of the water supply system—not alone in the light of economy as labor saving devices, but a means of obtaining 24-hour regulation and uninterrupted service.



Combined Pressure Reducing and Back Pressure Valve

These valves, a combination of two or more of our four standard automatic valves, may be arranged to control flows or pressure in one or both directions through the valve. Two or more hydraulic pilots or solenoid pilots, or combination of both, may (as conditions require) be a part of the external control. To those of us who have not had experience with a combination valve, it may be advisable to refer to one or two of these valves.

Sketch No. 7. In this sketch, two separate systems are illustrated:

Zone No. 1 with a normal pressure of 80 lbs and Zone No. 2 with a normal pressure of 50 lbs. The problem assumed is one in which Zone 1 can assist Zone 2 which (during periods of high draft) experiences a lowering of pressures. Other conditions involved are the excessive pressures which Zone 1 may place on Zone 2; and the possible overdrafting of Zone 1, particularly in the event of fire in Zone 2. Also, in the event of fire in Zone 1, priority must be given to Zone 1 for fire flows.

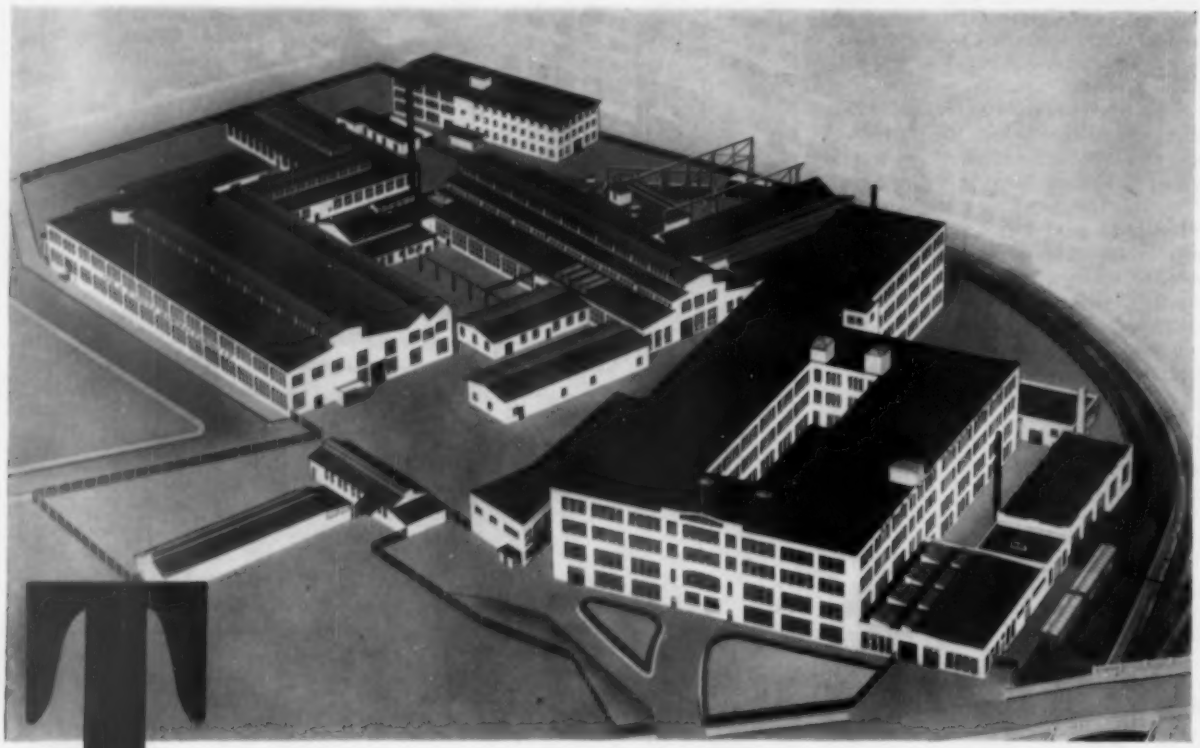
The valve which will meet these requirements is a combination valve having two hydraulic pilots in series—one to control the valve as a pressure reducing valve so that discharge into Zone 2 is held to a predetermined pressure; the other pilot to control as a back pressure valve and insure against overdrafting Zone 1. The valve, therefore, is a combination pressure reducing and back pressure valve.

The predetermined safe pressure for Zone 2 is 60 lbs—therefore, the pressure reducing pilot has the responsibility of delivering the safe pressure. Obviously, Zone 1 is to have priority; therefore, to avoid overdraft by Zone 2 in event of fire or break in this Zone 2, a predetermined pressure adjustment on the back pressure pilot is to provide the necessary protection. If this adjustment is 45 lbs, and for any reason consumption in Zone 2 is excessive (and the pressure in Zone 1 becomes less than 45 lbs) the valve closes or throttles.

The following will identify a combination altitude and back pressure valve controlling a tank—operating in conjunction with pumps taking suction from the tank. This valve is to pass water into the tank (however for two predetermined back pressures on the distribution), close to prevent overflow; and, when pumps are taking suction, the valve remains closed to prevent circulation thru the valve to tank.

The conditions of operation as planned are such as to require three hydraulic pilots and two solenoid pilots. In performing automatic operations as above, two hydraulic back pressure pilots are in parallel (one in series with electrical solenoid and pumps—the other hydraulic pilot in series with solenoid to be manually operated by a switch located at a remote point.) The third hydraulic pilot, for closing to prevent overflow of the tank, is in series with the two parallel hydraulic pilots and their respective solenoids.

In conclusion, it can be said that the use of automatic valves has been, is, and will always be essential to the efficient operation of water works system.



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EAST ORANGE, NEW JERSEY

Valve and Hydrant Maintenance*

by HOWARD W. NIEMEYER

Superintendent of Distribution, Indianapolis Water Co., Indianapolis, Ind.

CONSUMER dependence on an uninterrupted public water supply has grown almost beyond belief within the past two decades or so. Mechanical refrigeration, air conditioning, water-cooled industrial machines and other modern uses are creating such a continuity of essential demands that there is no longer a satisfactory or convenient time to shut off water service. Simultaneously, public tolerance for interruptions even in normal domestic service seems to be disappearing. This demand for a higher standard of service will force the plant operator to give more and more consideration to valves and hydrants.

Systems with inadequate valving will require the installation of additional main-line valves to minimize the areas of service interruptions which cannot be avoided. Unvalved hydrant leads, particularly in critical areas, will need valving to eliminate main shutouts during repairs. More thought will have to be given to the selection of the type of valves to be installed in large feeder mains for operation against unbalanced pressure. Particular attention must be paid to the design and structure of valves, to insure their endurance for the life of the pipeline so that they themselves will not be a cause for service interruptions to effect their repair or replacement. A preventive maintenance program for valves and hydrants, which has always been good operating practice, has become a must in perpetuating their readiness to serve.

It is unfortunate that valves and hydrants are not self-sustaining. The infrequency of their use may lead to the false assumption that they are not subject to wear and therefore remain in good operating condition without attention. The converse is more likely to be true, however, in that lack of use may be more detrimental than frequent operation. There are numerous forces at work which can cripple or destroy their usefulness for the purpose for which they were installed.

Corrosion

Probably the most serious distribution system problem today is corrosion. One phase of this problem has resulted from the promiscuous use of unprotected dissimilar metals in the structure of system components. Cast iron and bronze have long been the common metals used for water works materials. Separately they have an excellent record of endurance, but, suspended together in a solution, they produce galvanic corrosion. The rate and effect of this corrosive action in valves and hydrants will depend on their design and on the mineral content of the water, but it is always detrimental. Until such time as this problem is fully recognized and solved in either metal or structure design, the plant operator's difficulties will continue. It may be noted that galvanizing of the iron parts has been tried with some degree of success, but experience with this type of protection is insufficient to determine its long-range effectiveness.

In any corrosive action, there is a loss of metal, which results in a weakening of the affected part. If it is a working part subject to operating strain, progressive corrosion can eventually lead to failure. Equally as serious in valves are the products of corrosion, which form on the surfaces of moving parts and reduce or eliminate entirely the essential clearances needed for their freedom of movement. Periodic operation of valves will break off the corrosion deposit and help maintain the required clearances. Valves that have not been used for many years may be found to be entirely inoperative, because corrosion has swelled and then welded the moving parts into an unmovable, oversize mass.

Corrosion in hydrants does not exist in the same degree as in valves since the moving parts normally remain relatively dry. This situation changes, however, if the hydrants are set in an area of ground water that is sufficiently high to submerge their lower operating parts. Then corrosion can make their condition deteriorate enough to cause failure.

The stuffing-box gland of valves and hydrants is another source of difficulties presenting maintenance requirements. Corrosion that is primarily galvanic also takes place at this point and fills the clearance space about the stem with deposits. The most serious effect of this action is the increase in torque required to operate the affected valve and hydrant. Periodic operation will tend to work the deposit out of the gland and keep the operating stem moving freely, while neglect will allow the deposit to grow and harden until the stem becomes tightly wedged in the gland.

Of course, periodic operation of the valves and hydrants will cause a disturbance in the packing material in the stuffing gland. If this material has lost its resiliency, the gland will start leaking. This condition is not a problem in hydrants since they can readily be repacked, and it does not become a problem in valves until they leak continuously with the stem collar seated against its socket. A valve that leaks only during its operating cycle is a fault which is not serious enough to warrant the expense of the pavement cutting necessary to install new packing. Packing failures are sufficiently common, however, to require careful selection of the material to be used. The most satisfactory packing will be one that is noncorrosive, has permanent lubricating qualities, will not dry out and will seal with a minimum clamping pressure. Experience indicates that only a few types of packing will meet all of these requirements.

Street Improvement

High on the list of causes of valve and hydrant difficulties is street improvement and maintenance work. Experience would indicate that street contractors and city maintenance crews do not share the plant operator's view of the importance of keeping the utility's appurtenances in readiness for emergencies. Apparently they consider valve boxes and vaults as objects to be destroyed or buried, and fire hydrants are merely bumping blocks for bulldozers and road graders. Rigid inspection of all known street improvement jobs is necessary to see that all valve boxes and vaults are in position and properly graded. It is helpful to make a survey in advance of the construction work and to drive reference stakes along property lines to mark the location of all valves. It is also good practice to install new packing in the valves and to perform any other needed maintenance before a new pavement surface is put in place. If aditional valving is advisable in the area of the street improvement, it can be installed without paying the high cost of pavement cutting and repairing. In addition, hydrants may have to be relocated to suit changes in curbings.

Street improvement or major resurfacing projects can be watched to guard against damage to the distribution system parts, as the utility will have advanced notice of such work. It is the street maintenance crews, who cannot be followed, that are responsible for the large number of valve boxes covered or destroyed each year. Asphalt patching crews can be depended upon to cover with bituminous material any valve box in the area of a street repair. Road graders used on the unimproved streets will regularly break or tear up valve boxes without such damage being reported to the utility. The time lost by the utility in emergencies because of these artificially created difficulties can be quite serious.

Homeowners, in regrading their lawns, may either extend a terrace or cut the grade around a hydrant located at the property line. In the former situation, the hydrant nozzles may be so close to the ground as to interfere with the connection of a fire hose. In the latter, the hydrant is left standing high in the air, an unsightly object, and frost may penetrate to the base because of insufficient earth cover. Owners also have built fencing so close to a hydrant that it prevents the spinning of the operating wrench. These home projects which create hydrant hazards are seldom reported.

Effects of Traffic

Traffic can result in unfavorable conditions. Valve boxes located in an unstable road bed may be shifted by traffic loads so that the operating key cannot be engaged with the valve key nut. Boxes may be tilted so that a protruding edge becomes a hazard to pedestrian traffic. Vaults may become weakened, leading to the danger of a cave-in under traffic.

Hydrants are also traffic casualties and can be damaged in unreported collisions so as to render them useless to the fire department. They may be knocked out of alignment, the nozzle threads injured, the nozzles knocked loose in their sockets, or the base assembly damaged by an impact. In one hydrant, a test showed the barrel to have been broken in two, yet the hydrant appeared to be in good condition. If such damage is not reported to the utility, it must be found by regular inspection, or the faults may continue to exist until a hydrant is needed for fire fighting.

In replacing collision-broken hydrants, it is well to inspect their setting to determine if they need be relocated to a less vulnerable position. Hydrants should be set a safe distance from a curb and as far from street intersections as possible. The breakoff type of hydrant has many advantages and merits careful consideration. A collision with this type does not result in an emergency, and, since the broken section is readily discernible, a prompt report will probably be made to the utility. Furthermore, repairs can be made without shutting off the main.

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Rensselaer

VALVES AND HYDRANTS *with Mechanical Joint*

Mechanical Joint Hydrant.

Mechanical Joint Tapping Valve with "O" Ring Seal.

The surest way to reduce installation costs and insure long service with low maintenance on cast iron pipe lines is to use Rensselaer Valves and Hydrants with Mechanical Joints.

The installation cost is reduced because an unskilled laborer can make the connection in a few minutes with only one wrench.

Low maintenance is assured by the dependability of this type of connection which has been tested and proven in thousands of installations.

Rensselaer Gate Valves are built rugged and simple, designed to give positive seating action and long life. They are easy to operate, are made of high quality materials and conform to A.W.W.A. specifications.

Rensselaer Fire Hydrants are designed on the knuckle joint principle and open with the pressure. They are quick opening with free-flow, long radius curves. Will not freeze or flood and no digging is required for repairs or standpipe breakage.

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Freezing Climates

In freezing climates, where hydrants must drain for wintertime service, tree roots are always a source of difficulty. The importance of keeping the drain ports open is obvious. It is a good practice during the winter to check all hydrants as soon as possible after their use by the fire department. Non-draining hydrants should immediately be drained with a handpump to keep them in readiness for additional service until a maintenance crew can open the drain ports. Clogged drains can often be opened with compressed air to avoid an excavation job. The installation of a piece of copper wire or tubing in the hydrant drainage bed to stop root growth has been suggested.

Much damage can result to valves and hydrants through their use by inexperienced or unauthorized persons. Valves may be left partially or completely closed. Hydrants may be damaged or left partly open. Hydrant caps may be left loose or not replaced at all. To safeguard against these irregularities, all valve and hydrant operations should be strictly confined to the distribution system maintenance division, and operation by any other plant personnel or by outsiders such as street contractors, construction workers or contractor main-laying personnel should be prohibited. Temporary hydrant connections occasionally required by outsiders should be furnished by the utility with the installation of a hand wheel valve on a hydrant nozzle, leaving the hydrant open for the duration of the use. Such hydrant operation should be reported to the fire department. This policy assures that full knowledge of all valve changes will be available to the division responsible for distribution system emergencies, and it limits all operations to experienced personnel.

An exception to the above policy will, of course, have to be made for the fire department and city street-flushing and sewer-cleaning crews. There should be a special effort to give these groups instruction in the proper use of hydrants. A sectional hydrant can be furnished by the utility for training purposes.

All instructions should particularly emphasize the importance of replacing all nozzle caps as tightly as possible. Failure to do so is an invitation to trouble from the younger generation.

Testing Programs

Ample illustrations have been given to prove the need for periodic inspection of valves and hydrants if they are to be maintained in a ready-to-serve condition. Should the many faults that can and do develop be left to accumulate over a period of years, the plant operator might find himself in a desperate situation when a real emergency arose. The frequency of periodic inspections varies, but generally a yearly interval is adopted. The hydrant testing program is preferably conducted during the fall since most faults develop in the spring and summer. Autumn testing also allows conditioning of the hydrants ahead of winter service requirements. There is no particular seasonal advantage for valve testing.

Complete and accurate maps and records of the distribution system are essential in establishing the testing programs. Simply stated, a valve cannot be tested if there is no record of its installation. Numerous water works publications have described map and record systems that are considered good practice. It is suggested that, in addition to the standard system records, it is worth while to have a permanent test report card for each valve and hydrant. Such a card carries a complete description of all physical data regarding each installation—make, size, type, location, measurements from reference points, date of installation, identification number and a test route number. In addition, the valve test card should show the type of setting (box or vault), the number of closing turns and the direction of turning, if any plant operator is so unfortunate as to have mixed directional valves in his system. A 5 x 8-in. card will allow enough horizontal lines for at least 30 test reports, using both sides. Vertical columns with headings of items to be reported will permit the testing personnel to use check marks, requiring only a minimum of writing. The cards should be filed in the office by route number and should be taken out in the field only in quantities sufficient for a day's work.

The use of test report cards has a number of advantages: Once an efficient testing route has been developed, it can be followed for all subsequent tests. There is less likelihood that any valves or hydrants will be missed. The tester carry with them, in convenient reference form, complete information regarding each installation, and also have the benefit of all past testing history, so that they are aware of any abnormal condition that may exist. A considerable saving in paper work results.

As previously mentioned, the existence of both left- and right-hand valves in a system is an unfortunate circumstance, particularly if there is an absence of maps and records which accurately specify the operating direction of each valve. It would appear that valve operations are confusing enough to warrant the conversion of all valves to a single operating direction.

The testing of valves and hydrants requires the operation of the devices through their entire cycle, as partial operation is insufficient to establish their true condition. The purpose of the inspection is to determine readiness to serve, which can be judged only from a complete test.

Minor Maintenance

During the test deficiencies other than faulty operation should be detected almost automatically, and certain items of minor maintenance should be performed as part of the testing program.

The hydrant work should include lubrication of the operating nut, tightening or replacement of the stuffing-gland packing as needed, greasing of the nozzle cap threads and calking of loose nozzles. Obstructions to the visibility of the hydrant and poor condition of paint should be noted in the test report. It is also suggested that, since travel time is a considerable item in the inspection cost, other types of surveys can be incorporated in the program at slight added expense. Little time is required for the testing crew to listen in on each hydrant with some type of mechanical or electronic leak detector. A pressure survey of the entire distribution system can be readily obtained by having the crew install a nozzle cap equipped with a pressure gage. Some utilities take a pitot measurement of each hydrant's delivery rate, while others have the testing crew flush all hydrant leads and some dead-end mains. Three men can test about 120 hydrants in an eight-hour day. The addition of a leak and pressure survey to the program will only reduce the number of hydrants tested in the same length of time to 100.

The maintenance work which can be incorporated in a valve testing program is rather limited because the valves are inaccessible unless installed in vaults. Stuffing-box packing can be replaced or tightened in vaulted valves, if required. Likewise, geared valves can be cleaned and lubricated as needed. Maintenance of buried valves during testing is limited to finding and adjusting the height of valve boxes in dirt streets and cleaning boxes of obstructions. Hard-turning valves and those which will close only partially should be worked until they operate freely. It has been found helpful in working a hydrant branch valve to open the hydrant sufficiently to secure a scouring velocity through the valve. Sometimes a scouring velocity can be obtained through main-line valves by closing off a section of main in back of the valve and opening a hydrant leading off this section. Even valves with kinks in the stem which allowed only partial closure have been worked until the valve operated freely through the kinked section. The operation of these faulty valves is considered an important part of the testing program. Each valve which can be conditioned in this manner eliminates a main shutoff, a street excavation and the need for opening the valve in order to make repairs.

Power Operation

In the author's opinion an adequate and satisfactory job of valve testing cannot be done manually. Even if all the valves were in perfect condition, the physical requirements for testing a system of any size would place a considerable strain on the personnel. It is not possible to operate faulty valves manually in the way previously discussed. Power operating equipment is available for such work and should have preference.

One method of power operation is the use of a compressor-driven air motor of low speed. This type has the advantage of reaching valves inaccessible to trucks, but there is a drawback in that the air motor must be held by the crew in opposition to the turning torque of the valve. As in manual testing, the valve turns must be counted and there is always a likelihood of error, particularly in operating large valves which require a great many turns.

Another method employs a truck-mounted operating head powered by a takeoff from the truck engine. The head can be mounted on the right-hand side so that valves near a street curb can be reached by the operator with the truck going in the direction of traffic. With the right-hand mounting, the revolution counter, which is part of the equipment, is installed on the truck instrument panel, enabling the testing personnel to synchronize the flow of power with the registered position of the valve faces. Damage to valves is avoided by the use of multiple shear pins in the driving linkage, varied in number to suit the size of valve being tested. This type of power testing has made a hard job easy and has been used with most satisfactory results for all sizes of valves, even down to 4 in. Excellent results have been obtained with it in conditioning valves.

Valve and hydrant defects reported by the testing crew should be repaired as quickly as possible, the inoperative ones being given initial preference.

Hydrant painting is not connected with the testing program but is a maintenance job that should also be performed on an established schedule. The selection of the color to be used should be based entirely on visibility, particularly at night. The frequency of painting will be determined by the durability of the paint and the exposure of the hydrant to grime and dirt. Some utilities paint the hydrant bonnets and caps according to a color code which denotes the delivery capacity of each hydrant. This practice is an aid to the fire department.

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For over 50 years, more Trident meters have been purchased than any other make. Most of these . . . even the oldest . . . are still running accurately. This long serviceable life means lower amortization, obsolescence and replacement costs.

Trident meters have long led the field in design improvements, and today are the finest, most modern meters available. Every improvement has been made to fit all older Tridents. This is one of Trident's biggest advantages.

A planned schedule of testing and repair with Trident meters gives you a continuous program of meter modernization . . . at far less cost than scrap-and-replace methods. Repairs take less time, too, aided by Trident's extreme simplicity. A moderate stock of only the *latest* parts services *all* your Tridents. You waste no time searching or waiting for parts for old meters. Trident parts are *always* available. Your repair men have no obsolete models to learn. If they can repair one Trident, they can repair all . . . efficiently, economically.

TRIDENT METERS FOR DOMESTIC SERVICES IN COLD OR WARM CLIMATES

Trident meters combine fine-instrument construction with the inherent high accuracy achieved only in disc-type, positive displacement water meters. Accurate at all rates of flow within normal test flow limits and remarkably sensitive to small flows.

Trident Frost-Proof Meter embodies the original frost-proof meter feature. If the water freezes and expands, the cast iron bottom cap breaks, relieving the working parts from strain. The bottom cap can be replaced at very nominal cost. For warm climates, the Trident Split-Case Meter is recommended.

Among exclusive features for long accurate life are: Gear train is fully oil-enclosed, including the stuffing box, to isolate vital parts from abrasives, turbulence, corrosive elements, and to provide permanent lubrication. Anti-friction thrust roller absorbs disc thrust, making the Trident virtually immune to disc breakage. Heat-proof, hard rubber bushings in gear train and register are interchangeable. Sand ring keeps abrasive material out of working parts. Materials are corrosion-resistant, with special materials for unusual corrosion problems.

Easy to service and repair . . . makes big savings in meter costs over the years. Register has no screws. Chamber is snap-joint. Disc is in three parts, easy to adjust. Guide pins, slots, etc., assist in assembling meter properly.

Trident Frost-Proof Meters

Size In's	Wt. Lbs.	Lgth. In's	Wdth. In's	Ht. In's	Base to Center of Pipe	*Del. U.S. Gal. Min.
⅝	10⅝	7½	5½	8⅝	1⅝	20
⅝ x ¾	11½	7½	5½	8⅝	1⅝	20
¾	15	9	6	8⅝	1¾	30
1	26	10⅝	9⅝	9½	2	50
1 x 1¼	26	10⅝	9⅝	9½	2	50

Trident Split-Case Meters

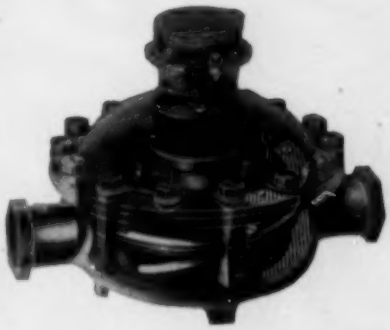
Size In's	Wt. Lbs.	Lgth. In's	Wdth. In's	Ht. In's	Base to Center of Pipe	*Del. U.S. Gal. Min.
⅝	9	7½	5	7⅝	1	20
⅝ x ¾	9½	7½	5	7⅝	1	20
¾	12	9	5⅝	8⅛	1⅞	30
1	20	10⅝	7½	8⅝	1⅝	50
1 x 1¼	20	10⅝	7½	8⅝	1⅝	50

NEPTUNE METER COMPANY

STYLE 3 TRIDENTS FOR MEDIUM RATES OF FLOW

A disc-piston meter for commercial and other installations requiring medium rates of flow larger than household consumption, but not great volumes. Also excellent for "battery" settings where preferred for metering wide flow ranges. In addition to sensitivity on low flows inherent in disc meters, it has the Trident oil-enclosed gear train, heat-proof removable bushings in register and gear train, interchangeable parts and other Trident features which give it sustained accuracy and low maintenance cost. On 1½" and 2" sizes, a "delivery adjustment" can be regulated in relation to line pressure to prevent racing.

These two sizes of Style 3 Meters do the work of any compound meter of equivalent size and, being simpler, they do it with less cost for maintenance and repair.



Trident Style 3 Meters

Size In's		Wt. Lbs.	Lgth. In's	Wdth. In's	Ht. In's	Base to Center of Pipe	*Del. U.S. Gal. Min.
1½	Scr.	36	12⅝	10	10⅝	2⅝	100
1½	Flge.	40	13	10	10⅝	2⅝	100
2	Scr.	58	15¼	12 5/16	11⅝	3¼	160
2	Flge.	61	17	12 5/16	11⅝	3¼	160
3	Flge.	195	24	16 5/16	17⅞	3½	300
4	Flge.	257	29¼	22 1/16	20⅝	4⅜	500
6	Flge.	589	36¾	29	25⅝	5⅞	1000

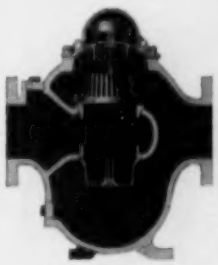
CREST METERS FOR BULK WATER DELIVERIES

For "bulk" water deliveries at periodic or continuous high rates of flow—i.e., where mains deliver water to adjacent townships; hydraulic elevators, cranes, pile-jetting apparatus, etc., the Crest Meter is recommended. Of the velocity type, a turbine is rotated by the water at a speed directly proportional to rate of flow. Among features is the hollow hard-rubber turbine revolving on agate bearing, resulting in minimum friction, maximum sensitivity, sustained accuracy. Standard Trident register and gear train features. All parts interchangeable.

Trident Crest Meters

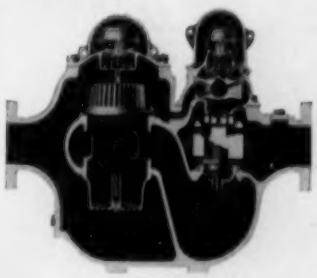
Size In's		Wt. Lbs.	Lgth. In's	Wdth. In's	Ht. In's	Base to Center of Pipe	*Del. U.S. Gal. Min.
1½	Scr.	65	12⅜	8½	16¼	6⅝	100
1½	Flge.	65	13	8½	16¼	6⅝	100
2	Scr.	83	15½	8⅞	16⅝	6⅞	170
2	Flge.	85	17	8⅞	16⅝	6⅞	170
3	Flge.	250	24	13⅝	27¼	13¼	400
4	Flge.	260	24	13⅝	27¼	13¼	700
6	Flge.	300	24	14⅝	28⅝	14⅜	1600
8	Flge.	500	26¾	17½	30¼	15⅝	2800
10	Flge.	800	30	26⅝	29¼	13⅞	4400
12	Flge.	1200	36	30½	34⅞	16½	6400
16	Flge.	1950	42	36½	40⅞	19⅜	12400

Am. Wt. Wks. Asso. & New Eng. Wt. Wks. Asso. Std. Specifications



COMPOUND METERS FOR WIDE WORKING RANGES

Use this Compound Meter for services with a maximum demand beyond the range of equivalent disc meters—yet with the probability of occasional small rates of flow. Accurate over a wide working range. Measures high rates of flow through a Trident Crest Meter unit and small flows, which cannot be recorded accurately by the Crest, through a Trident Disc Meter unit. In addition to the standard Trident features of both these meters, a specially constructed valve automatically directs the water to the proper unit, depending on rate of flow. Single cast iron casing. All parts interchangeable.



Trident Compound Meters

Size In's	Wt. Lbs.	Lgth. In's	Wdth. In's	Ht. In's	Base to Center of Pipe	*Del. U.S. Gal. Min.
3	460	33	13⅝	27½	13¼	220
4	475	33	13⅝	27½	13¼	500
6	685	36½	14⅝	28⅝	14⅜	1000
8	970	42	17½	29⅞	15⅝	1600
10	1500	45 7/16	20⅝	29⅛	13⅞	2300

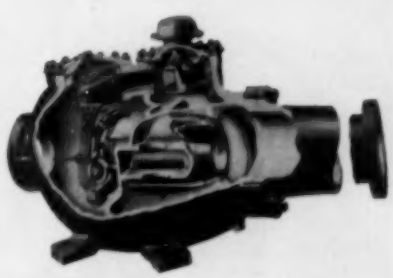
PROTECTUS METERS FOR FIRE SERVICE LINES

Designed for fire line use where both high and low flows occur, and loss of head is an important factor. Meets such requirements with (a) accuracy on all flows and (b) low loss of head plus reliability of operation, satisfying both Water Works officials and Underwriters. Measures low flows through a Trident Disc Meter unit. Large flows are measured proportionally by a Trident Crest unit. Water-way is clear, unobstructed. Both units have standard Trident features which insure accuracy, long life and low maintenance cost.

Trident Protectus Meters

Size In's	Wt. Lbs.	Lgth. In's Incl. Incr.	Wdth. In's	Ht. In's	Base to Center of Pipe	*Del. U.S. Gal. Min.
3	700	64⅝	22⅝	21½	8	400
4	900	67	24	24⅝	8	700
6	1600	83⅞	29	27½	10	1600
8	2250	89¾	32⅝	30½	11⅝	2800
10	3400	98½	38½	37⅝	14⅝	4375

Am. Wt. Wks. Asso. & New Eng. Wt. Wks. Asso. Std. Specifications



NEPTUNE METER COMPANY
New York 20, N. Y.

See Page R-190 for Branch Offices and Factories

Layout of Meter Maintenance Shop*

by DAVID J. FORD

Asst. Sales Mgr., Ford Meter Box Co., Wabash, Ind.

MANY water works men are faced with the task of laying out a new meter-testing shop or improving the arrangement of an old one. The numerous advantages to be gained from the use of proper equipment, well located in the space available, justify careful study and planning. The following suggestions on what to use and where to place it may be of some help.

Meter shops range in size from those for repairing and testing a few dozen meters a year to some which work on more than 10,000 annually. In addition to the number of meters, other conditions that can affect the size, equipment, and layout of the shop include:

1. Number of makes and types of meters used, which governs the size of the repair part stock and the storage space for it.

2. Local water quality, which determines the extent of corrosion, liming, incrustation, and wear.

3. Location and type of meter settings, which control the condition of the meter register and the outside of the casing. The repair of frozen meters is sometimes a tremendous job in certain meter shops. In other localities, meter casings become caked with mud, and, when the dial glass is broken, the entire register may be mud clogged.

4. Local practice of state requirements specifying how often meters shall be tested.

5. Customer ownership of meters, which calls for special care in identifying and segregating meters so that they can be returned after testing.

6. Existence of special cleaning practices in refurbishing meter casings during the process of repair and testing. Whether done by wire brushing, acid dipping, sand blasting or painting, special equipment is required.

In planning the equipment and layout of any meter shop, some or all of the above factors must be borne in mind. Possibly more important than any of them is the trend toward increased numbers of meters and toward more frequent repair as they become older. All planning should be done with an eye to the future.

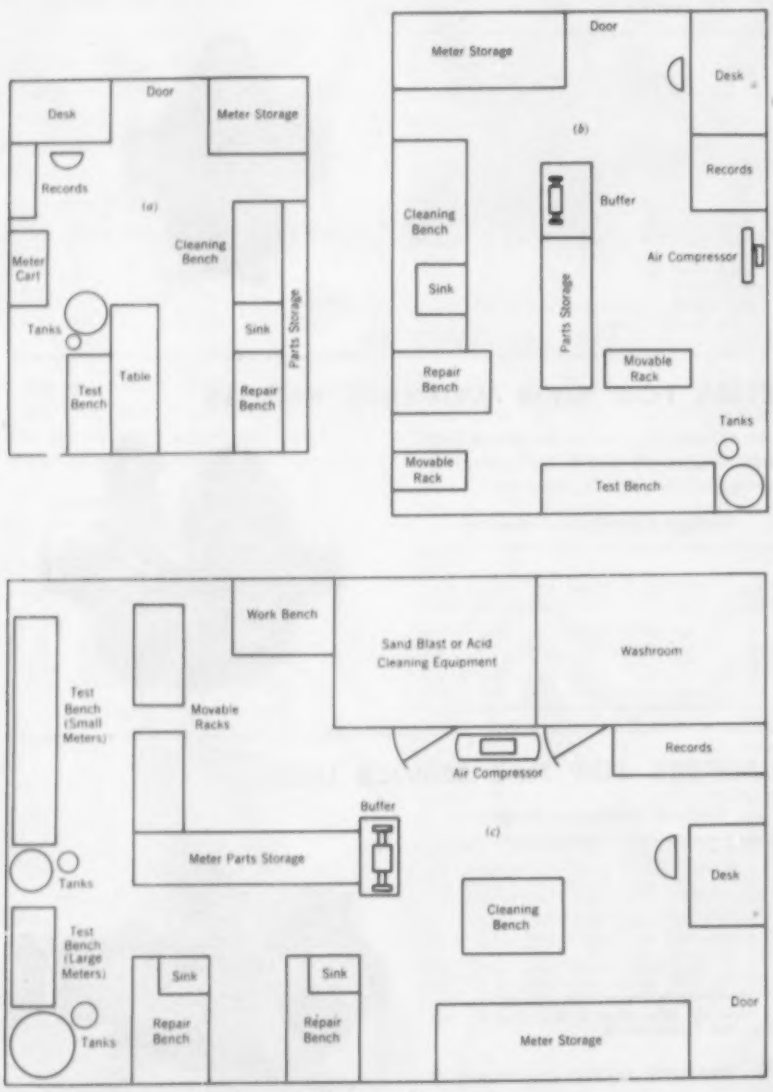


Fig. 1. Suggested Shop Layouts
Key: (a) 12 x 15 ft; (b) 15 x 20 ft; (c) 30 x 20 ft.

Selection of Equipment

The basic equipment, exclusive of a desk or file for meter records, is listed below. The most essential items are given first, followed by those which would be justified only in large shops:

1. An accurately calibrated tank, or a plain tank on an accurate scale, to check the meter being tested against the actual volume causing a given registration. Drainage piping for the tank (or tanks) should be of sufficient size to empty it quickly.

2. A substantial workbench with vise, hammer, wooden or leather mallet, screwdrivers, wrenches, pliers, files, scrapers, wire brushes, and other tools.

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3. A sink with running water, preferably both hot and cold, for washing meters and parts.

4. A test bench for domestic-size meters (through 1 in.). Although meters can be connected up with ordinary fittings, there is a saving in time and effort if a test bench is used for smaller meters, which probably constitute up to 99 per cent of the total tested. The number of test units on the bench would be governed by the volume of work. Series testing is generally economical. For more efficient testing, benches may provide for hydraulic clamping of meters and automatic shutoff of flow at the proper tank level.

5. A rate-of-flow indicator.

6. An electric grinder, with wire brush and buffer, which has a wide variety of uses.

7. Storage bins or drawers for meter parts.

8. An adapter for testing 1¼-, 1½-, and 2-in. meters. This accessory, which can be attached to the test bench, provides ease of testing of larger meters at a minimum investment.

9. A small air compressor. Only experience will indicate the many ways in which compressed air is convenient for cleaning, drying, painting, and similar operations.

10. A bench drill press or an electric hand drill, a widely useful device. Electrical outlets should be conveniently located.

11. Chemical cleaning equipment. Experts disagree greatly on the advisability of using acids or other chemicals on meter parts. The cleaned pieces, especially when treated with acid, have a fine appearance but may be slightly reduced in size, so that meter performance is affected. When chemical cleaners are used, precautions must be taken to prevent health hazards. Proper rinsing facilities and exhaust fans should be provided.

12. A test bench for 1¼-, 1½-, and 2-in. meters. When enough large meters are to be tested, a special bench for one or more of them is a good investment. Calibrated tanks large enough to hold water for tests run at high rates of flow are also desirable for quantity testing of large meters.

13. An electric or air-driven impact wrench. This provides for the speedy removal of large meter casing bolts.

Lack of equipment need not result in poor testing of small meters. With an accurate tank, a watch, and a few valves and fittings, it is possible to do a thorough testing job. Some or all of the additional items listed above will, however, increase efficiency and are usually a good investment.

Shop Layout

After the amount and type of equipment to be included in the meter shop have been decided upon, attention should be given to proper placement in the allotted space. There are a number of requirements to be satisfied and a good many valuable principles to be applied. The arrangement adopted should provide the best flow of meters through the shop. The distance between adjacent stations should be short, and easy methods of moving the meters should be available.

Basically, a meter in the shop follows this general routing: the incoming meter is tested and stored; next, it is washed and disassembled; the parts are cleaned, nonserviceable parts are replaced, and the meter is reassembled; then it is taken to the test bench and given the required tests; if its accuracy is within the limits prescribed, it is sent to outgoing storage; if further repair is necessary, the meter is returned to the repair bench, and part of the cycle is repeated.

The nature of this cycle suggests the necessity for good material-handling practice to simplify as much as possible the physical work involved. This objective can be approached by:

1. Locating the meter shop on the ground floor. This eliminates elevators and speeds up supply.

2. Arranging for a loading dock near the door of the meter shop. This also will shorten the distance supplies

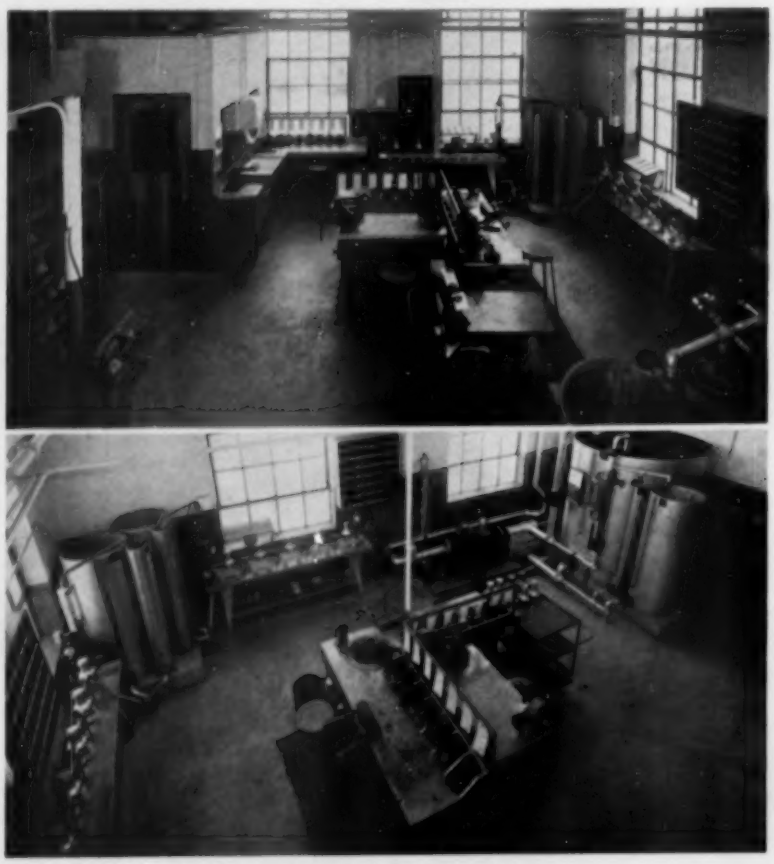


Fig. 2. Two Views of Wichita, Kan., Meter Shop

In the top photograph, the storage racks are visible in the left foreground, with the grinder and buffer a little to the right; at rear left is the acid cleaning room, flanked by a sink and workbench; test benches and tanks for small meters are at rear right; in the right foreground, part of the large-meter testing equipment can be seen; at center are other workbenches, with a portable rack for small meters in front of them. The lower photograph, taken from atop the acid room, gives a good view of the small-meter test benches and the center workbenches. Behind the large-meter tanks at right rear, the drill press is partly visible. The shop area is approximately 625 sq ft.

must travel.

3. Maintaining good lighting, either natural or artificial, throughout the shop. Work tables should be arranged so that the light from the windows does not shine into the repairman's eyes. Good operation in a meter shop depends upon the ability of the workmen to see what they are repairing, inspecting, or testing—jobs in which clear vision is all important.

4. Providing for both hot and cold running water. Washing meter parts with hot water and soap is the most harmless method in use and is sufficient for many parts. Hot water is essential, especially in cold weather.

5. Locating a motor-driven buffer near the repair bench. It is important to have this machine within a very few steps of the repairman, to avoid continual walking. The buffer should be equipped with a dust collector or exhaust.

6. Washing the exterior of dirty meters when they begin the processing cycle. This practice will improve working conditions by producing a much cleaner meter shop.

7. Making compressed-air hoses available to both the repairman and the meter tester.

8. Providing storage space for both incoming and outgoing meters near the door. There they can be easily counted and readily moved in or out.

9. Placing the meter record file near the door and the meter storage area.

10. Keeping commonly used parts on the repair bench and storing other parts nearby for easy access.

11. Avoiding extensive paper work in the parts checkout procedure. Time will be saved and the repairmen will be appreciative.

12. Equipping the shop with carts or rolling racks to be used for moving meters from one station to another and for storing meters. Each rack or cart should hold a specified number of meters so that quick inventory can be taken. It should be easy to reach every meter and read its tag. In a small shop, ten meters per cart would be enough; in a large shop, 100 meters arranged on a rack would be more efficient. It may be desirable to provide facilities for hooking meters on the rack in a vertical position. With that system, each meter is on the outside of the rack and can be removed or examined without disturbing any other. Dock facilities can be arranged so that an entire rack filled with meters can be rolled alongside a track for loading, thus eliminating one handling operation. The benefits from mobility of meters should not be underestimated; any practice that will speed up the processing cycle is worth serious consideration.

It is usually impossible to adhere closely enough to theory to attain the ideal layout, chiefly because existing facilities impose limits upon the designer. It is cheaper to work such facilities into the layout than to alter them to fit the ideal. It may, however, be worth while to compare the cost of changing the existing facilities with the value of the increased efficiency made possible. The features affecting meter shop design include: shape and size of room; existing piping; location and size of windows, doors, and columns; size of available equipment, such as filing cabinets and workbenches; and availability of space for meter and parts storage outside the room. The latter condition can be an advantage if there is not enough space inside the room for storage. Otherwise, to have the storage in another room means wasted steps every time a part or meter is moved.

The three suggested layouts illustrated (Fig. 1) serve to demonstrate the principles mentioned previously. The prevailing conditions determine the layout. In the small-shop layout (Fig. 1a) the meters move clockwise about the room with only short distances between adjacent stations. The layout in Fig. 1b provides more storage space, a buffer, more bench space, and a larger test bench. For larger cities, the arrangement in Fig. 1c provides for two separate repair benches, two test benches—one for smaller meters and one for meters larger than 1 in.—a cleaning room, and a washroom. Movable racks are shown in all three layouts. Figure 2 illustrates an actual layout.

Meter shop layouts embodying the principles of efficient material handling, using proper equipment, and having real regard for the workman's needs can definitely save time as well as labor.

Acknowledgment

The author wishes to acknowledge gratefully the many helpful ideas gained through consulting and corresponding with E. J. Good, Indiana Gas & Water Co., Lafayette, Ind., and with H. W. Niemeyer and A. McCauley, Indianapolis Water Co., Indianapolis, Ind.

R&D

Renovating Water Meters

Water Companies, on the whole, and also several of the more progressive municipally owned Water Departments, have found that a little dressing up of overhauled meters before returning them to the customers' service has a desirable psychological effect on the customer. The spray gun and gilt or silver lacquer or a combination of the two is the most universally employed method of dressing up old meters after they have been overhauled and tagged "O.K." on the test bench.

Mr. La Verne Trentlage, Superintendent of Meters in the Water Department of Elgin, Ill., has evolved a scheme which goes the spray-gilting method one better in making "new" meters out of old ones. In the Elgin scheme the metal parts of the meter are given a treatment which removes the oxidized or carbonated coating from the metal and leaves the parts as metal-bright as when turned out by the manufacturer.

Cleaning and Brightening Procedure

(1) Dip meter parts for 10 minutes in *hot* Trisodium Phosphate solution (2½ lbs. or more of T.S.P. in 10 gallons of water).

(2) Remove meter parts from T.S.P. solution and rinse in *hot* water to remove the alkali.

(3) Dip the parts in Muriatic Acid solution (1 part 18 degree Muriatic Acid—to 2 parts of water). Allow to remain in this acid bath for approximately 15 minutes, or longer if necessary. Remove and rinse in hot water.

(4) To brighten to original lustre, immerse in the "bright-dip" solution (1 part 38 degree Nitric Acid, 1 part 66 degree Sulphuric Acid and 1 part water, plus a handful of common salt). Leave the parts in the bright dip for 5 to 10 seconds, the length of time depending on the composition of the metal and degree of brightness desired.

(5) Remove and rinse in *boiling* water to remove acid.

(6) To keep the parts from dulling on standing, a "stabilizing-dip" (especially prepared for this purpose) has been developed by General Chemical Company). After the rinse, the parts are dipped into this solution, removed and allowed to drain and dry.

Notes of Caution: Always add acids to water and *not* water to acids when making dilutions. This will preclude over-heating and spattering of the acid. Be careful to avoid splashing of the acid when dipping the meter parts. In case acid accidentally splashes on hands or face, wash at once in clean water to avoid an acid burn. Spattered acid is also hard on clothing and shoes. Rubber aprons and gloves are good protection.

Do not use iron or steel wire for dipping meter parts. Copper or monel metal wire is satisfactory.

Compressed Air Flushing of Small Mains

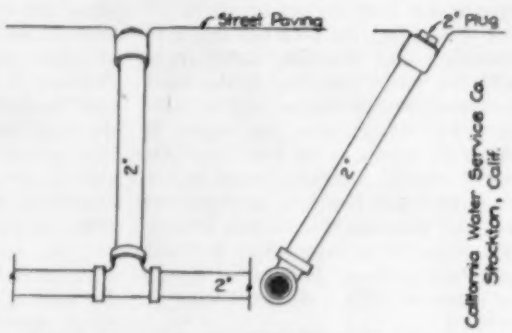
by R. F. BROWN

Plant Manager, California Water Service Co., Stockton, California

MANY water systems in the older California towns, like Topsy, just grew without any suggestion of planning for the future. Stockton was no exception. As a consequence we found ourselves with a great many 2-inch lines in the thinly populated areas.

We have for many years followed the practice of flushing small mains and all dead ends regularly by opening fire hydrants and flusher valves and simply allowing the water to flow from the main under normal pressure of 45 pounds until the main is apparently clear. Under this program all dead ends and all small mains are given ordinary flushing, approximately at intervals of every two months.

This method, however, does nothing but freshen the water in the dead ends and small mains. In order to effect a more lasting cure for taste and odor complaints, we decided to try boosting the pressure in the main with air to attempt to break loose more of the troublesome algae and other deposited material that attaches to the pipe wall. All of our dead ends, regardless of size, and at least every other block of our 2-inch lines have what we call flusher-risers installed for the convenience of our periodical flushing program—see sketch.



RISER CONNECTION TO 2" MAIN FOR FLUSHING

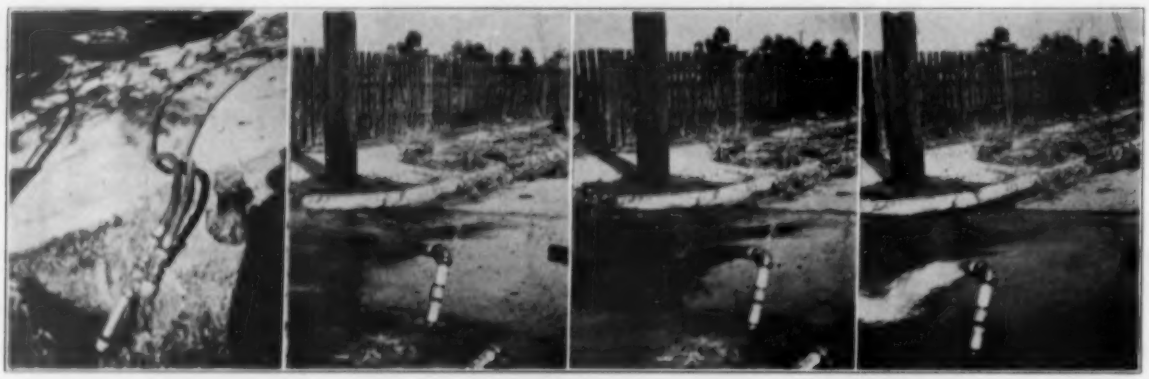
pose and it is economical, because the equipment required is only a portable air compressor and an air storage tank to provide a volume of air under pressure. No expensive cutting of mains or pavement is required and most jobs can be handled with a three-man crew.

When we first started this system we cleaned 40,000 feet of line, mostly 2-inch, over a period of two months. The cost was from 60 to 90 cts. per hundred feet, depending upon the number of services which had to be shut off and turned on again.

The success of this method of flushing is measured by the almost complete absence of the usual recurring taste and odor complaints from consumers served by mains thus treated. It is problematical how soon we will have to repeat this treatment, because from no consumer on the first line so treated has there yet developed a recurrence of complaints.

A secondary result, not anticipated, is the increase in carrying capacity of the 2-inch lines brought about by the loosening and blowing out of a great deal of scale. Thus has resulted a reduction in complaints of poor pressure as well as the taste and odor complaints.

A Self-Told Story



Air lines connected (this time through house service at curb line)

First 90 lb. air shot. (Note extension attached to flushing-riser)

First 45 lb. water flush. (No argument about need to eye or nose)

Clean water (shooting and flush repeated as indicated)

Air Flushing Operations

Compressed air is put into the line through a service connection midway between two flusher-risers after we have first closed the shut-off valves on the intervening services. The valve on the flusher-riser is then opened. All water in the line is forced out through the riser, by air under 90 pounds pressure. As soon as the air has expelled all the water from the line it is shut off and water under our ordinary pressure is run through the line to sweep out, through the flusher-riser, all particles of scale, sand or foreign matter that have been loosened by the air "shooting." We proceed in this manner alternately turning into the line air under 90 pounds pressure and water at 45 pounds until the flushing water leaving the risers no longer carries with it any scale or other foreign matter.

This system is apparently successful in accomplishing our pur-

WATER TREATMENT

THE TREATMENT of water for domestic or industrial use is commonly termed water purification. This is a relative term; it refers to the removal of undesirable matter (suspended and dissolved) and bacteria in order to make the water acceptable for use.

The kind of treatment employed in water purification depends on the use for which the water is being prepared and the character and amount of the matter to be removed. For domestic use, that is, for human consumption, removal of bacteria is of primary importance, but removal of turbidity, color, tastes and odor is also desirable from the standpoint of the consumer. Industrial processes, too, often require more elaborate purification than water for domestic uses.

The steps in water purification include several unit processes: Coagulation, sedimentation, filtration, disinfection, aeration, adsorption, chemical oxidation, ion-exchange, chemical precipitation and stabilization. Aeration, adsorption and chemical precipitation are used in softening and iron and manganese removal. Stabilization is a method of corrosion control. These steps not only involve unit processes but also special equipment.

Coagulation and Sedimentation

Coagulation is accomplished by the addition of chemicals to water. This involves the use of chemical handling equipment, chemical feeders and chemical feeder controls, mixing and flocculation equipment, and tanks in which the necessary reactions can proceed.

Sedimentation provides for the removal of suspended or precipitated matter by allowing these particles to settle under the influence of gravity. Sedimentation is accomplished in tanks which are designed to produce the desired detention time and are equipped with valves, level controls, and devices for removing the settled sludge. Some of these latter devices are mechanical and provide for continuous removal of the sludge.

The subject of coagulation and sedimentation and chemical handling are discussed under Section IV of this Reference & Data Edition.

Filtration

When water is passed through beds of porous material, suspended matter is removed. The common material used in water plants is relatively fine sand although crushed anthracite is also used. This sand is contained in some structure with a valve system for controlling the flow of water and an underdrain collection system. There are two types of filters; slow sand filters through which water is passed at rates of 0.016 to 0.16 gal per sq ft per min and rapid sand filters through which water is passed at rates of 1.6 to 3.2 gal per sq ft per min, sometimes at higher rates.

The actual removal of suspended and colloidal matter by filters is accomplished in several ways. Particles larger than the voids between the sand grains are strained out and form a mat, termed a Schmutzdecke, which in turn strains out smaller particles. Precipitation of colloids by adsorption on the relatively large surface of the sand grains also removes matter. There is also a flocculation which takes place in the filter and these flocs build up on the surface of the sand grains thus increasing the area of the surface which can adsorb matter.

Microorganisms also aid in the filtration process. They form sticky coatings on the sand particles which attract and hold other particles. These organisms may also act on these substances and actually cause a chemical change to take place. This is particularly true in slow sand filters.

Most treatment plants in the United States use rapid sand filters (sometimes called mechanical filters from the early designed which used mechanical rakes in cleaning). Filter plants are usually constructed with several units which operate in parallel. Usually, the number of units is some multiple of two and the size of the filters is such that each can treat an appreciable percentage of the maximum daily load on the plant. The capacity of the filter may be from 25,000 to 10 million gallons per day. In designing the filter plant, it is generally planned to have a reasonable number of units of reasonable size.

The filter consists of an underdrain system commonly termed a filter bottom, of which there are several kinds (Wheeler bottom, porous plate, perforated tile, brass strainer, etc.). Above the filter bottom there is usually a shallow layer of coarse gravel on top of which is a layer of 24 to 30 in. of fine sand, the size of which is important. In place of silica sand, crushed and graded particles of anthracite coal is also used.

Valves are used on the inlet to the top of the filter, and on an outlet to the sewer, also above the filter and connected to troughs above the sand to carry off wash water. An outlet valve and rate controlling valve are used on the effluent line from the underdrain system of the filter. Another valve is placed on the effluent line to waste and another on a wash water line which is connected to the underdrain system for forcing water upward through the sand for washing.

An instrument to determine the loss of head through the filter indicates the extent to which the filter has become clogged by accumulations of dirt. This is known as a loss of head gage. A gage is also connected with the rate of flow controller to show the rate at which water passes through the filter and to totalize the amount filtered. Each filter is usually equipped with an operating table which controls the opening and closing of the various valves.

When the filter becomes clogged with impurities removed from the water, the loss of head increases and eventually reaches a point where the filter will not pass water at the desired rate. It is then time to wash the filter. This is done by shutting off incoming water, closing the effluent valve, opening the surface waste outlet, and opening the wash water valve to admit water to the underside of the filter.

The object of filter washing is to remove the filter sand, all the matter accumulated thereon during filtration. Passage of water upwards through the sand or anthracite coal ("Anthrafilt") at rates of 15 to 30 inches of rise per minute is enough to lift the sand particles and cause them to scour against one another. The rate at which wash water is applied, as measured by the rate of rise of water level, is controlled to prevent sand being washed out of the filter, but should be high enough to cause the sand bed to expand by 50 percent.

The length of the washing period will vary for different conditions but generally three to five minutes is sufficient. To improve the scouring action on the sand grains during washing high pressure water jets are used at the sand surface. The Palmer filter wash uses rotating jets. Air may also be injected at the bottom of the filters. Uniform distribution of wash water throughout the area of the filter is essential to good washing. At the end of the washing period, the valving system is adjusted to accomplish filtering again, but the first water through the filter is wasted. Water from the filter goes to clear water storage usually after chlorination.

Disinfection

Not all of the bacteria in water are removed by filtration and some water supplies are not turbid enough to require filtration but do contain some bacteria. In both cases (and with well waters too), a chemical agent is added to destroy these bacteria or assure that none will grow. This process is intended to kill off harmful bacteria and not necessarily to kill every single organism. Therefore, it is termed disinfection rather than sterilization.

The most common agent used for disinfection is chlorine or a hypochlorite compound which will release chlorine. This subject of chlorination is discussed in Section V of this Reference & Data Edition and will not be discussed at this point.

Other agents used for disinfection include chlorine dioxide, bromine, ozone, ultra violet light and silver compounds. Chlorine dioxide has been used more for taste and odor control than for disinfection; bromine is used for swimming pool water disinfection; ultraviolet light has been used in industrial process waters and silver compounds only for small quantities of water.

Aeration

The purpose of aeration is to improve the quality of water, usually by removing unwanted tastes and odors or carbon dioxide. Aeration is accomplished by bringing the water into intimate contact with air. This contact may be brought about by aerators of several types. Air diffuser aerators introduce air from blowers through some porous media in fine bubbles at the bottom of a tank and the air passes upward through the water sweeping out the undesirable tastes and odors.

Waterfall aerators consist simply of a pipe for discharging the water at some height and allowing it to fall through the air; cascade plates, slotted plates, shelves, steps, etc. aid in breaking up the water as it falls. Spray nozzles probably create the greatest breakup of water particles and hence the largest surface exposed to air, but it requires considerable head to produce the spray. Many water plants operate aerators only when taste and odor problems exist, principally in the summer time when algae growths abound.

Taste and Odor Removal

Tastes and odors in water supplies come from natural or man made causes; natural sources include algae, leaves, decaying vegetation, etc. man made tastes and odors come from sewage and industrial wastes. Algae are generally the worst offenders.

The only practical method for measuring odors is the "Threshold Odor Test." Odor is evaluated by an operator smelling samples of the odorous waters that are diluted with various amounts of odor-free distilled water. The odors are vaporized by controlled heating in order to make it easier for the operator to make his observations.

The Threshold Odor Number is obtained by dividing the volume of odor-free dilution water by the volume of odorous water, when a dilution is reached above which the odor cannot be detected. Definite threshold numbers can not be set for all supplies but a hot threshold number of more than two can often be noticed by consumers.

Two methods are used for the control of tastes and odors due to algae. The first is to control the growth of algae in the water supply. This is termed preventive treatment. Copper sulfate added to the reservoirs in controlled amounts will kill off algae before the numbers of organisms reach proportions that will cause severe tastes and odors. Preventive treatment within the water plant includes good housekeeping, particularly by keeping coagulation and settling basins and filters clean.

Corrective treatment includes aeration, chemical oxidation, and adsorption. Aeration has already been discussed. Chemical oxidation includes treatment with chlorine dioxide, ozone, and chlorine; adsorption utilizes activated carbon.

Chemical Precipitation

Chemical precipitation is involved in coagulation to produce the floc desired, but it is employed to a greater extent in water softening by the lime-soda process. This subject of water softening including the ion-exchange process is presented in some detail in Section V as are iron and manganese removal.

Stabilization

Waters which contain carbon dioxide or have a pH below neutral for other reasons tend to be corrosive to mains and household services and hot water tanks. Waters which have a high pH due to softening tend to deposit carbonates in mains and services or to be corrosive to hot water tanks. Treatment to overcome both of these tendencies is stabilization; treatment to prevent corrosive action is commonly termed pH adjustment or corrosion control and the word stabilization is more generally applied to treatment of softened waters which are super-saturated with calcium carbonate, or which are low in alkalinity due to excess lime treatment.

Stabilization of lime softened waters may be accomplished by recarbonation with carbon dioxide gas, by the addition of alum which is both acidic and flocculates the carbonates, or by the addition of sodium hexametaphosphates, of which Calgon is an example. Treatment with the glassy phosphate is known as "threshold treatment" because a very small amount of phosphate will inhibit excessive precipitation of the carbonate.

Fluoridation

The addition of fluoride compounds, termed fluoridation, is not a treatment method in water purification. Rather it is a process of adding a chemical to the water supply as a carrier in order to provide a micronutrient to the diet of the consumers. It has been shown that the presence of approximately 1 ppm of fluoride ion in water will decrease the incidence of tooth decay in children and in adults who drink such waters regularly as a child. The addition of fluorides to water is a public health measure, and water works personnel and plants usually act only as the agent in carrying out the will of the people where it is decided that fluoridation should be practiced.

Laboratory Control

All water purification practices should be carried on subject to laboratory control. This subject of laboratory control has been discussed in Section IV.

Washing and Maintenance of Filters*

by JOHN R. BAYLIS
Engr. of Water Purif., Dept. of Water & Sewers, Chicago

IF the qualification for writing with authority on washing filters depended on the number of filters washed annually in the filtration plant, the author would qualify without question. During 1953 there were 38,579 filter washes at the Chicago South Dist. Filtration Plant. On one day there were 385 washes, probably an all-time record for any filtration plant. Some may wonder how the operating force managed to do this. The answer is simple: it was organized for just such an emergency. Several years of operation of an experimental filtration plant prior to designing the present large installation made it possible to predict that the emergency would occur some day. The experimental work also indicated what to do to lessen the number of washes. The filter plant staff was waiting for an actual occurrence to be fully convinced of the necessity of using the treatment to lengthen filter runs.

There is scarcely a plant in this country that does not have periods of short filter runs to add to other operating difficulties, although not many have such a wide range in clogging tendency as the Chicago plant. This statement was well demonstrated by operating one of the filters in the experimental plant on raw water with no coagulation and sedimentation. The filter bed was composed of sand 0.50 mm in diameter and was operated at a rate of 2.0 gpm per square foot. The runs to 8-ft loss of head varied in length from 1.5 to more than 100 hr. The material that clogged this filter was chiefly certain species of microscopic organisms occurring naturally in the water. The number of plankton was greatest when the water was clearest. These organisms are of the same specific gravity as the water, or they would not be distributed throughout it. With almost no other suspended matter in the water to give weight to the coagulation, the tendency to settle in the basins is not great.

If the water were of uniform quality throughout the year, it would not be difficult to design for the particular condition existing, but large variations in characteristics present a problem. The water being handled by the large filtration plant in Chicago is of the same quality as that in the experimental plant and is subject to the same wide range in clogging tendency.

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Filter Bed Troubles

If there is a good distribution of the wash water and proper grading of the filtering materials, nearly all trouble in the filter beds may be attributed to failure of the washing system to remove from the filter all material that has been taken from the water. When a clean bed of sand is put into service to filter water that has been coagulated and settled in the usual manner, and the filter is allowed to run until the loss of head increases to 8–9 ft before it is washed, it will be noted that some of the material filtered from the water cannot be removed except with a wash rate so high as to wash away part of the filtering material too. A portion of the mud or coagulated material has become so compacted that its suspension in water is almost the same as that of the filtering material, usually sand. The specific gravity of the mud particles is considerably less than that of the sand grains, but the particles are much larger, giving them a settling rate through water close to that of sand. If the mud particles are not broken up in some manner by an agitating force much greater than that produced by the backwash, they cannot be removed.

Each time a filter is backwashed without the aid of a surface wash, additional material filtered from the water is retained in the bed. The particles of mud become more compacted. Some of them build up to large size as more material adheres to them at the surface of the bed, or else the mudballs become pressed together so firmly during the filter run that they do not break apart at the next washing, but instead stick together to form greater masses. Usually some sand is mixed in with the mudball to give it additional weight.

The mudballs, when newly formed, tend to remain at or near the surface of the bed after washing. Eventually, however, they attain a specific gravity great enough to cause them to sink to the bottom of the sand bed during the washing period. At the same time that they are being compacted, they are being worn away gradually by abrasion of the sand during the backwashing periods. Many again become clumped together at certain points in the bed and some combine to form larger mudballs, or mud deposits, at the bottom of the sand bed or against the side wall of the filter. When the rate of wearing away is as great as the rate of formation, the volume of the clogged area in the filter does not increase. In fact, in many places, during certain seasons of the year, or under certain conditions of the water, the volume decreases. The decrease is most likely to occur in the colder months.

Washing Procedure

All filters have to be backwashed. In order to maintain the beds in good condition, many filters throughout the United States are now equipped with surface wash facilities to assist in thoroughly breaking up the mudballs and cleansing the beds. The procedure for washing filters should be developed with care. As an example of how filters are washed, the instructions to filter operators regarding the normal washing procedure at the South Dist. Filtration Plant are quoted:

The following procedure for washing filters and keeping filter log records is to be effective until further notice.

1. When to Wash a Filter

a. When the loss of head reaches 8 ft.

b. When the loss of head is approaching 8 ft on ten or more filters during short filter runs. During very short filter run periods, washing may be required before a 7-ft loss of head [is reached]. Filters with the greatest loss of head should be washed first.

c. When the filter has 48 hr of service, regardless of loss of head.

d. When the rate of flow on a fixed-rate filter (manual setting) begins to drop and the loss of head remains constant or continues to rise.

e. When the loss of head is 6-7 ft with a low rate of flow, on a filter operating at a variable rate of flow (master control setting), and an increase in demand is expected.

2. How to Wash a Filter

a. Close 30-in. influent valve and allow

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Anthracite Institute Building
WILKES-BARRE, PENNA.

ANTHRAFILT — an Improved Filter Medium

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Palmer Filter Equipment Company, 822 E. 8th St., Erie, Penna.

Anthrafilt and Its Application

Anthrafilt is made from a **selected** Pennsylvania anthracite which has been cleaned so as to have a minimum ash. This cleaned anthracite is then screened and classified hydraulically to yield sizes suitable for filter purposes.

Anthrafilt is used as a mechanical aggregate in place of sand and gravel in all kinds of filters, i.e.

Rapid gravity filters	Slow filters
Swimming pool filters	Pressure filters
Hot process softening filters	Oil removal filters
Cold process softening filters	Alkali filters
Mechanical sewage filters	Acid filters
Revolving screen filters	Sewage sludge-beds
Portable filters	Household filters

The entire filter bed may be made up of Anthrafilt of various sizes or only the top layer may be of Anthrafilt over the usual bed of gravel.

Advantages of Anthrafilt

High Filtration Rate: Rates up to 200 mgad are obtainable with Anthrafilt without sacrifice of effluent quality. The accepted average rate with sand is 125 mgad.

Long Filter Runs: The larger, irregular Anthrafilt grains allow less clogging with algae or other fibrous substances. The angular grain surfaces provide greater entrapping areas for the removal of turbidity and bacteria. The differences in shape and specific gravity of the grains, by decreasing classification after back washing, allow the whole depth of the filter bed to be active in the filter operation.

Low Wash Water Costs: The long filter runs and consequent less frequent washing and the low degree of packing after back washing combine to cut the usual wash water requirements at least in half.

No Cementing with Lime, Manganese or Iron: Lime will coat on Anthrafilt but this coating readily flakes off without any cementing action if filters are properly operated. Manganese and iron salts precipitated on Anthrafilt by the lime treatment are easily removed by back washing.

High Degree of Expansion: 50% expansion is obtained with half the back wash velocity required for sand.

Coarse Sizes Can Be Used: The irregular shape and natural filtration characteristics permit the use of much larger sizes with equal results.

Gravel Beds Stay Flat: No ridging or mounding and less cracking and pulling away from side walls during operation.

Low First Cost: Lighter weight per unit volume balances the cost differential between Anthracite and sand and saves on freight and handling charges.

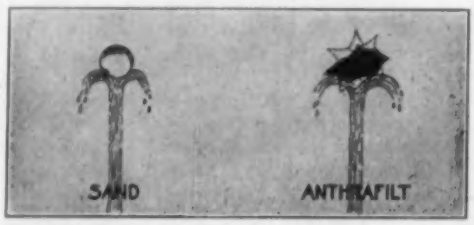
Filtration Characteristics

Anthracite granules are irregular shaped and of varying densities. Weights run about 53 pounds per cubic foot as against 100 pounds for sand. The irregular shapes provide greater porosity resulting in more rapid filtration with no loss in character of effluent and with considerably less loss of head.

The variable densities of Anthrafilt particles cause less classification after back washing and the lighter, irregular shapes allow easier expansion and more effective cleaning.

The greater bulk of Anthrafilt requires less tonnage per filter bed. Attrition losses amount to less than 0.25% per year.

Anthrafilt successfully removes lime, iron and manganese salts and will not form a permanent coating under proper conditions of treatment and filter operation. Lime flakes off easily without cementing and the iron and manganese salts are readily removed by back washing. Oil is easily removed from boiler water after coagulation with ferric sulphate, ferrous sulphate or alum. Anthrafilt can also be used for the filtration of acetic and sulphuric acids and caustic soda solutions. Being insoluble in alkaline waters, Anthrafilt produces silica-free water in hot process water softening.



Upward impulses of water produces greater agitation of angular grains, hence Anthrafilt beds are cleaned more effectively.

Anthrafilt No. 1 is usually made in sizes ranging from effective size of .60 m.m. to .80 m.m. the uniformity coefficient is less than 1.75 in all sizes. We can make smaller sizes or larger sizes, but for special cases only. The remaining sizes of Anthrafilt are as follows:

No. 2. Anthrafilt—3/32"x3/16"
No. 3. Anthrafilt—3/16"x5/16"
No. 4. Anthrafilt—5/16"x9/16"
No. 5. Anthrafilt—9/16"x13/16"
No. 6. Anthrafilt—13/16"x1-5/8"
No. 7. Anthrafilt—1-5/8"x2-7/16"
The above sizes have 20% tolerance.

ANTHRAFILT ECONOMY

When Used in Existing Filtration Plants

Increased capacity with same plant
Decreased volume of wash water
Lower maintenance cost through elimination of ridging, mounding and air binding.

When Used in New Filtration Plants

Lower plant investment
Lower cost per cubic yard
Lower wash water costs
Lower maintenance costs

the water to filter down until the water level is between the surface wash jets and the surface wash laterals. (Filters on master control, whose rate of flow has dropped almost to zero, may be "dumped." Filters that have stopped filtering because of high loss of head during short filter runs may also be dumped. Under no other conditions should filters be dumped, except by approval of filtration engineer. Record dumped filters on daily filter log. *Caution:* When dumping, do not open drain valve more than 7½ in. After dumping is complete, open drain valve fully.)

b. Close 20-in. effluent valve, open 42-in. drain valve, and turn on the electric switch to the sand expansion gage.

c. Start opening 30-in. backwash valve. When it begins to move, open 12-in. surface wash valve 6 in. Hold surface wash valve open for about 45 sec on filters in which the water level has been lowered to the surface wash jets, and about 30 sec on those in which the level cannot be lowered below the tops of the troughs. A 15-in. opening of the backwash valve will give maximum washing rate. The backwash rate is controlled by adjusting backwash rate controller to give about 3-in. sand expansion which varies with water temperature. Hold backwash valve open at maximum rate for 3 min. If, after 2 min of washing, the backwash water clears up to the extent that the surface wash laterals located about 10 in. above the sand surface are visible, the backwash valve may be closed.

d. Air binding. Filters in which the water level is allowed to go below the sand surface, and those in which the rate has fallen off because of an excessively high loss of head, may become air bound. When backwashing these filters, the air should be released slowly, in order to avoid sand eruptions. Therefore, the backwash at the beginning of the wash should be at a low rate (about 5 mgd).

3. Placing a Filter in Service

a. Close drain valve.

b. Partially open the influent valve (about 5 in.) to avoid a rapid rush of water that may disturb the sand surface. After nearly filling the filter, open the influent valve fully.

c. Open the effluent valve. Check to see that the rate controller opens up. If it does not open, check pilot valve. It may be necessary to bleed the rate controller system.

d. Turn off the electric switch for the sand expansion recorder. . . .

4. General

a. It is imperative that the instructions for filter washing procedure be followed. No deviation from these instructions is permitted without specific permission from the chief operating engineer or the filtration engineer on duty. Such deviation in washing procedure should be noted in the remarks column of the filter log sheet.

b. The procedure . . . of turning on the lights in the filter gages when a filter is ready for washing, to give visual indication to filter operators of filters needing washing, is an excellent one. . . .

c. Good filter washing operation requires that the filter washings be distributed as evenly as practical throughout the shift. Do not bunch the washes in a short period of time during the shift, for such a procedure places an excessive load on the wash water and drainage system, and indicates poor operation.

All fitration plants, with the possible exception of those operated by one man, should have a written procedure for washing filters. The procedure should meet local conditions and need not be so specific or extensive as the one given above. The procedure should be flexible enough to take care of special conditions. To illustrate, when the filter runs are short, the washing period usually need not be as long as under normal conditions. Much depends on the rapidity with which the waste wash water clears as the backwashing continues. Some plants have set a limit of turbidity—generally 10 ppm or so—for the waste wash water.

To collect a sample of water and test the turbidity while the washing is in progress would be impractical, but, by taking samples at the end of the washing periods and testing them, the operators soon become familiar with the appearance of the wash water and can guess the turbidity very well. In the South Dist. plant, the cast-iron surface wash laterals are located approximately 12 in. below the top of the wash water troughs. When the water clears so that this piping can be seen distinctly, the turbidity generally will not exceed 10–15 ppm.

Many operators continue the wash until they can see the surface of the bed clearly. In the absence of any other guide, this rule is satisfactory, although it tends to prolong the wash unnecessarily. In a number of plants, a specified period of backwashing is prescribed, and the operators do not deviate from it under ordinary conditions. Such a procedure generally requires the use of extra wash water, because the length of the period is set to meet the worst conditions. It does, however, insure that the filters will be washed thoroughly.

Clogged Areas

In the days before surface washing was adopted, many filter beds throughout the country acquired an abundance of mudballs and clogged areas. It was not uncommon to see mudballs an inch or more in diameter almost covering the entire surface of the bed. The accumulation of mudballs in certain parts of the filter soon started the formation of clogged areas, which usually deflect the backwash in such a manner as to add more mudballs to the mass.

The worst clogging occurs around the side walls. In some instances, filter beds have been pulled away from the side walls, making a crack almost to the gravel layer. This condition is caused by a slight shrinkage of the bed as the loss of head on the filter is increased. Side filtration occurs through the crack, and a layer of coagulated material that filters from the water forms on the side, just as on the surface of the bed. When the filter is washed, this layer is pressed against the side wall of the filter and generally is only partly removed by the backwashing. Figure 1 is a photograph of clogged areas in a filter bed.

The only way to prevent side-wall clogging is to keep the sand grains so clean that the bed will not shrink during its period of service. The purpose of the surface wash is to break up the mudballs before they become sufficiently compact to settle to the bottom of the sand bed. Another fact not generally recognized by operators is that a mudball is much more likely to sink to the gravel surface with high expansion of the sand bed than with low expansion. The very high rates of backwashing used in a few filtration plants tend to defeat their objective, in that they cause the mudballs to sink to the gravel more easily. When they once settle to the gravel layer, only a backwash rate great enough to disturb the gravel will generally be able to move the mudballs. Because much has been written about mudballs and clogged areas, an extensive description of the troubles they produce and the means of preventing their formation need not be given in this paper.

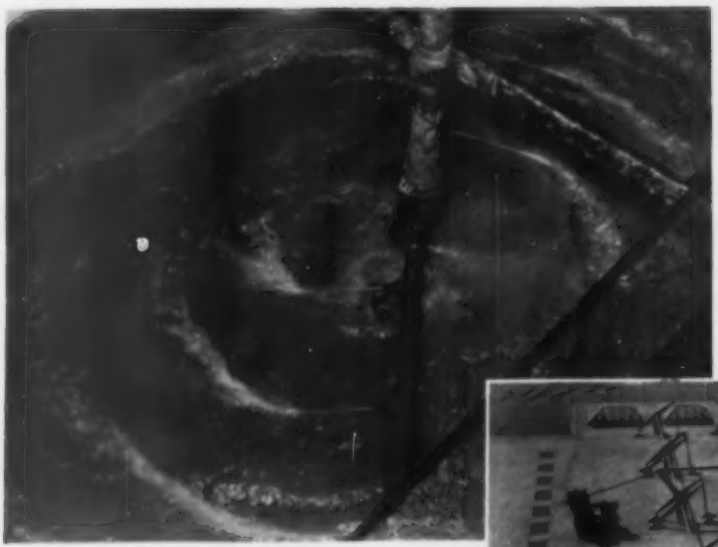
Surface Washing

For years the prevailing principle in filter bed maintenance was to wash the sand very gently so that the supposed biological film on the surface of

Fig. 1. CLOGGED Areas and Cracks
Mounded sand is noticeable along the side wall of the filter.

SIX REASONS WHY...

You Should Specify



Palmer Surface Wash

PALMER SURFACE WASH SYSTEMS

1. Prevents Sand Beds From Cracking.
2. Eliminates Mud Balls.
3. Saves Wash Water.
4. Lengthens Filter Runs.
5. Gives Higher Rates of Filtration.
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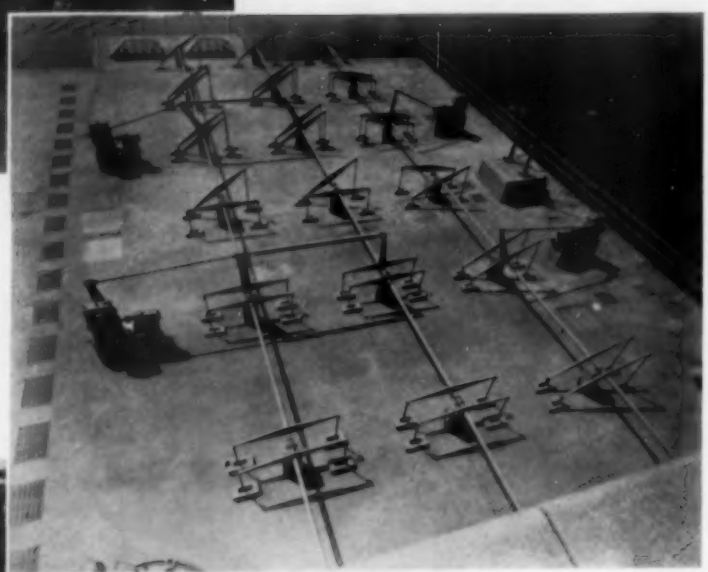

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1. Eliminates troublesome underwater bearings.
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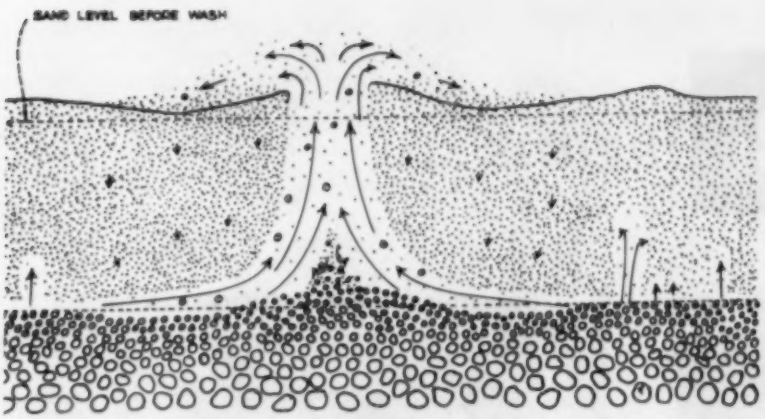

Fig. 2. SAND Boil Formation

The diagram shows a sand boil forming at the start of the wash. At the same time gravel is being pulled toward the boil and is piling up at the bottom of it.

the sand grains would not be removed. This idea probably was a carryover from slow sand filtration. Now it is known that it is far better to have a clean filter bed than film-coated sand grains.

Several methods of agitating the bed had been tried in the past. For example, revolving rakes were employed to prevent clogged areas in the round wooden filters used so extensively years ago. Although there were a few early tests of surface wash jets, this method did not make much headway until after the construction of the Chicago experimental filtration plant in 1928. Surface wash jets were installed in all of the filters in that plant and proved so effective that the system was soon extended to other filtration plants. As previously mentioned, it is rapidly becoming the practice to equip all filters with surface wash facilities.

The surface wash consists of a system of pipes that expel jets of water into the sand bed at the surface in such a manner as to break up the mudballs when they start to form. Several methods of applying the jets of water have been used. A fixed jet system generally produces more rapid breaking up of the mudballs, but revolving jets have proved adequate and very helpful in many filter beds, despite the much longer period of operation generally needed. There have been so many faulty installations of homemade fixed jets that a few operators have been led to believe that they are not satisfactory. Homemade fixed jets must be installed properly if they are to give the best results.

Valve Difficulties

The backwash valves in most filtration plants become leaky after a few years of use. This statement refers to double-disc gate valves with cast-iron bodies and brass seat rings. The double-disc valve, although suitable for distribution systems, has to operate in backwash lines under conditions for which it is not basically designed. Such valves work under the highest water head of any on the filter piping. Designers of filtration plants often place the wash water tank too high. There is scarcely a filtration plant in which the backwash valves do not leak after a period of service ranging from 5 to 10 years.

Analysis of the pressure on valves during closing and opening reveals the weakness of many types. The discs are held away from the body rings by guides until ready to seat. Just before seating, the pressure of the water is transferred against the face of the downstream body ring by the disc assembly sliding off the guides. The discs then are wedged against the body rings. Opening the valve produces so much stress on the guides to raise the disc assembly that the metal is gradually crushed. The guides wear and soon allow the ring on the disc to make contact with the downstream body ring before the valve is closed. Both the disc and body rings become scarred, resulting in water leakage. The higher the head of water, the more quickly a valve will begin to scar.

So far the only remedy found has been to replace the valve, or at least the rings. Encouraging results have been obtained with a rubber-seated butterfly valve, but is has not been in service long enough for its life span to be determined conclusively. Easily replaceable valve seats and guides are the best that can now be hoped for.

Small four-way valves that operate the larger hydraulic valves have been a source of difficulty from the very beginning of rapid sand filtration and probably will continue to be troublesome so long as they are used. A four-way iron plug valve, greased at frequent intervals, may be better than the ordinary brass type, but greased valves require a separate water system—although few filtration plants have one—to avoid getting some of the grease in the water, or to discharge the hydraulic-cylinder water to waste.

If four-way valves are used, closing the pressure line to the manifold to which they are connected, after the filter has been washed, may be helpful. The four-way valves often become hard to turn with the levers provided. The leakage through such valves generally is not great and does not affect their operation.

Expansion of Sand Bed

Filter operators are aware that, as the backwash valve is turned on, the sand surface rises and a heavy concentration of coagulated material previously filtered from the water soon overflows the wash water troughs and drains out the waste pipe. Within 3–4 min the water clears sufficiently for the backwash valve to be closed. If the washing is continued a few seconds longer, the surface of the sand may be seen, first dimly and then, after 60–90 sec, very clearly. The expanded sand rises several inches above the filtering level, and moves about in a partly suspended state. In some places, boils occur, accompanied by rapid movement of the sand across the surface. Elsewhere the movement is less rapid but erratic. The speed of movement is much greater than can be accounted for by the average upward velocity of the backwash water.

Observation of the backwashing operation in a small filter with glass sides would give a better idea of what takes place in the sand bed than can be obtained by watching the surface of large filters. When the backwash valve is opened, the sand does not expand gradually, with the grains merely moving farther apart, but jets of sand and water rush upward in places at considerable velocity. Within approximately 30 sec after the backwash valve has been opened, the sand surface rises to its maximum height during the wash—3–6 in., or even more, above its level when at rest, depending on the rate of backwash.

The rate of backwash for the large

Roberts Filter *means . . .*

MUNICIPAL WATER PURIFICATION

The combined capacity of Roberts-equipped filtration plants is well over 5 billion gallons (5,000,000,000) per day. Regardless of the size of the plant or the nature of the filtration problem, Roberts Filter can be depended upon for equipment that is reliable in years of service.

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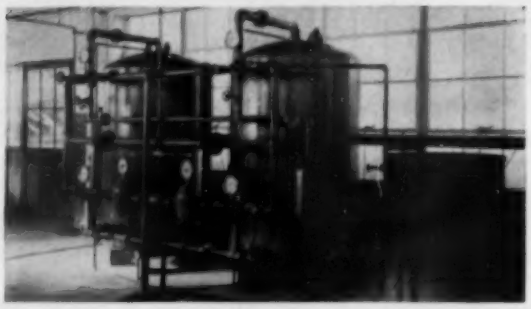

Water treatment has long been a specialty of Roberts Filter. Zeolite water softeners are guaranteed to meet all requirements for which recommended, and are available in a wide range of capacities. Roberts water conditioning equipment is widely used to control precisely the desired chemical content of water for industrial use.

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The combination of thoroughly clarified water and efficient recirculation are features for which Roberts pools are famous. Systems for both outdoor and indoor pools are designed and installed by men long experienced in the conditions peculiar to a successful swimming pool installation.

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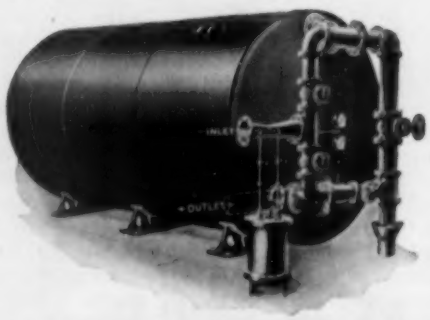

Closed pressure filters have wide usage where gravity filters are not justified. Roberts vertical filters are available in standard types from 12″ to 96″ diameter; horizontal pressure filters are all 8′0″ in diameter and in varying lengths from 10′0″ to 25′0″.

When you think of good water—think of Roberts Filter

MECHANICAL EQUIPMENT BY ROBERTS FILTER MFG. CO. DARBY, PENNA.

Roberts Filter

Manufacturing Company • Darby, Pennsylvania

filters at Chicago generally is set to produce 3–4 in. expansion of the sand bed, although most plants employ rates that result in greater expansion. The reason for the low rate at Chicago is that the surface wash is used to aid in cleansing the sand beds, making a high backwash rate unnecessary.

A backwash rate of 15 gpm per square foot of sand area would result in an expansion of 5 in. or so. At the South Dist. plant, a rate of wash just below 8 gpm is the maximum at which water can pass upward through the bed without lifting the sand. The 15-gpm rate would begin to lift the bed bodily above the gravel, with the production of a clear space between the sand and gravel, filled largely with water. Because the sand grains do not adhere, the entire bed of sand would not be lifted as a unit and remain suspended on a layer of water. Instead, the water would soon break through the bed in places, with large boils forming if the backwash valves were opened rapidly, and small boils if opened slowly. With rapid opening of the valve, the bed might be lifted 2–3 in. above the gravel before the water started to break through. Then great rushes of water and sand would be let loose at various points over the bed, usually several feet apart. Boils so great that some of the small gravel is thrown above the sand bed have been observed. Such rough handling of the gravel layers that were so carefully placed in the filter beds during construction is obviously undesirable.

Figure 2 is an attempt to show diagrammatically the formation of a sand boil. After the bed has been lifted above the gravel layer and is floating on water, weak points develop and holes open up, permitting water with a small amount of sand to rush out. If the sand bed is lifted only a little, it will cause gravel 2–3 ft away to be pulled toward the boil, and a pile 2 in. or more above the original gravel layer will form at the bottom of the boil. Repeated production of large boils in backwashing soon causes unevenness of the gravel layer, particularly if the boil occurs at the same spot a few times. Removal of the finer gravel layer in places may allow sand to come in contact with coarser gravel, leak through it, and pass out of the filter by way of the underdrains. This is not an uncommon occurrence in many filtration plants. In fact, very few plants never have sand leakage.

Jet Action. There may be other conditions that produce boils in filter beds. If a boil persists after the bed has fully expanded, rapid turning on of the backwash valve may be basically responsible, but jet action at the sand-gravel junction also may play a part. The term "sand-gravel junction" refers to that part of the filter where the material that is in motion during backwashing joins the gravel or material not in motion. The water does not pass from the motionless gravel to the partially suspended sand at a uniform velocity. In numerous areas, the water and sand travel upward at many times the average upward velocity of the water, while, at other places, the sand travels downward, somewhat as shown in Fig. 3. The result is a series of jets of water and sand over the area, at intervals of several inches. The velocity in the jet is so great that it will move gravel particles several times larger in diameter than the coarse sand grains at the bottom of the sand bed. With a backwash rate of 15 gpm per square foot, the average upward velocity of the water should be less than 0.1 fps. The velocity within the jets, however, appears to exceed 1.0 fps and is thus more than ten times the average upward velocity.

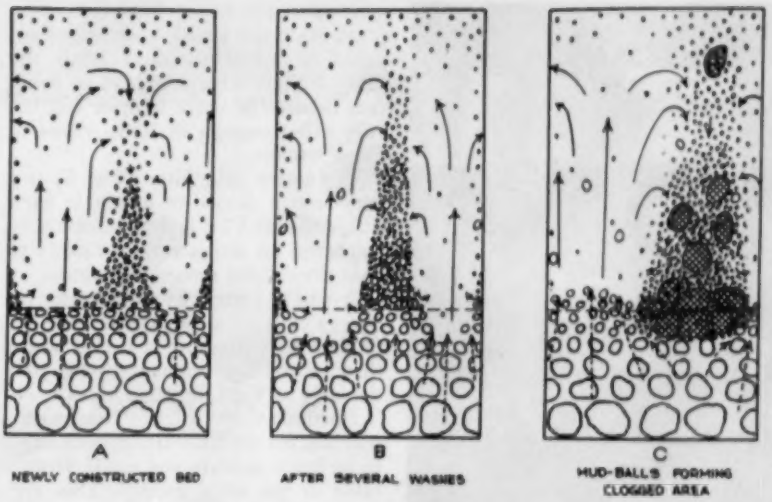

Fig. 3. Jet Action at Sand-Gravel Junction

Key: A—newly constructed bed; B—condition after several washes; C—mudballs forming clogged area.

Jet action is a natural phenomenon that will take place wherever water flows upward through porous material with a velocity causing that part of the material to be suspended. It is not confined to situations involving sand and gravel, but will also be produced where fine sand overlies coarse sand and the upward velocity suspends only the fine sand. The size and specific gravity of the material merely affect the velocity, size, and length of the jets, not their formation. Jet action can be observed in glass-enclosed or glass tube filters.

These jets of water and sand constantly disturb the fine-gravel layers and cause filter beds almost everywhere to reach such a state that they require occasional rebuilding. If mudballs are allowed to form in a filter, clogged areas often begin to develop at the gravel surface. Jet action is ideal for piling up the mudballs in numerous places at the gravel surface. As previously noted, prevention of mudball formation by surface washing is the best way to avoid clogged areas.

Sand Expansion Gage. Sand expansion recording gages have proved extremely effective in aiding filter operation. The time of wash, the sand expansion, and the rate of expansion of the bed are shown on a chart. This information provides an excellent check on how the filter operator is doing his job.

The instrument consists of a float riding on the surface of the expanded sand, a pneumatic transmitter, and a recorder. Fig. 4 shows the float and transmitter arrangement.

Specific Gravity. The specific gravity of the smaller sizes of gravel (1½–⅜ in.) should be not less than that of the sand. Otherwise, there will be a tendency for the lighter particles of gravel to mix with the sand, thus defeating the purpose of the fine-gravel layer. Not much attention has been given to specific gravity, for it does not make a great deal of difference if the larger particles have a relatively low specific gravity. When it is recalled that jet action at the junction of the sand and gravel will move gravel at least ¼ in. in diam-

Fig. 4. Sand Expansion Gage
The float rides the surface of the expanded sand. The pneumatic transmitter sends the signal to a recorder located elsewhere.

eter, the importance of its specific gravity becomes evident. The ideal condition would be to use gravel of greater specific gravity than that of the sand.

The influence of specific gravity was demonstrated in a glass-enclosed filter in which material of approximately 2.9 sp gr was placed over ordinary gravel. After a few backwashes it could be observed that much of the fine gravel had mixed with the filtering material, which was a crushed product of ordinary sand size but more angular than sand. Probably, some of the filter bed troubles attributed to other causes are actually the effect of low specific gravity.

Filter Appurtenances

Filters equipped with float-operated flow rate and loss-of-head gages generally require considerable attention. Cords or cables jump the pulleys or break, and have to be serviced. A pneumatic telemetering system has performed well at the South Dist. plant.

Valve position indicators give much trouble in plants. Flexible operating shafts have proved more economical than cables or cords with counterweights.

Antiquated filter rate controllers often are a source of considerable operating difficulty, and all controllers need some servicing.

Automatic control of backwash rate is attractive in theory but may not be practical where a wide-open backwash valve would wash sand from the filter. Failure of the control to function before the valve is open will occurr often enough in some plants to cause trouble.

The cotton plug filter (Fig. 5) is a very useful device to attach to each filter effluent. Floc detectors should be employed on filters that are likely to pass flocculated material at times.

A single butterfly valve in the recovery cone of a cylindrical tube decreases the surging of the water through the filter effluent piping, particularly at high filtration rates.

Pneumatic operation of the master controls for the filters enables changes to be made quickly and easily from a table in the filter gallery. This system is particularly valuable at times of peak demand, when it is desirable to maintain the filtered-water reservoirs at a high level.

Replacing Gravel and Sand

In the course of time it becomes necessary to rebuild the filter beds. In some plants, the beds have to be rebuilt almost every year, while, in others, they may continue in service for years without sufficient trouble to warrant rebuilding. That filter beds become disturbed is partly due to the design, but mainly to the character of the water.

If a filter begins to leak sand, it should be rebuilt, unless the sand leakage is at one spot and can be corrected without removing the sand and gravel from a large area. Only a skilled operator should try to remove and replace the gravel and sand in a small area of the bed.

In large plants, it is cheaper to rescreen the material if the gravel and sand have become mixed. For small plants, it generally is cheaper to purchase new material, properly screened to size.

Wash Water Troughs

More study should be given to the design of wash water troughs. Heretofore they have been designed to be just large enough to carry away the wash water. If the troughs could be made to occupy a greater volume of the space above the surface of the expanded sand, the turbid material on top of the sand bed would be washed away more quickly. Developments along this line should be sought in the future.

Conclusion

This paper has discussed some of the important principles and problems of filter washing and maintenance. It should be stressed, however, that attention must be given not only to the physical and mechanical aspects but to personnel matters as well. Proper design and operation must be combined with employee efficiency and responsibility in order to achieve the desired result—an adequate supply of safe, palatable water for the community.

Fig. 5. Cotton Plug Filter
This device is attached to the filter effluent line.

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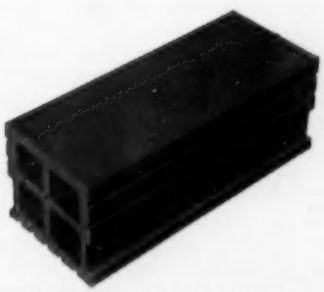

Each individual distribution block is about two square feet in area and weighs approximately 100 pounds.

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FILTER OPERATING TABLES • MIXER EQUIPMENT

Notes on Water Chlorination

THE USE of chlorine as a disinfectant is so widely established that the term "chlorination" frequently is used to mean disinfection but chlorine has other uses as well.

Chlorine is an extremely active chemical, prepared by the electrolysis of salt brine. It is purified, dried, liquefied by compression and cooling, and loaded into 105 or 150 lb. cylinders, ton containers or tank cars for shipment to consumers. The handling, use, and safety factors in chlorination practices have been discussed elsewhere in the Reference and Data Edition of *Water & Sewage Works.*

Purpose of Water Chlorination

Chlorine is added to water to destroy pathogenic and other bacteria. Chlorination is also used for taste and odor control, for chlorination of transmission mains to maintain carrying capacity, and to control slime growth in process and cooling water systems.

Types of Chlorination

When chlorine added to water has satisfied the chlorine demand, a residual is obtained. In the presence of ammonium compounds, either natural or added, chloramines are produced and may be measured as "combined residual chlorine." The treatment is known as "combined residual chlorination." If additional chlorine is added to pass the "breakpoint" (at which point combined chlorine residuals disappear), "free residual chlorine" is produced and the treatment is known as "free residual chlorination." Disinfection is more effective in the presence of "free residual chlorine," but this treatment requires greater chlorine dosage capacity than combined residual chlorination.

For some conditions, it may be advisable to add chlorine in amounts above that necessary to produce a nominal free chlorine residual. The excess is obtained by "super-chlorination" and the excess must be destroyed by subsequent "dechlorination," with sulphur dioxide, sodium sulfite, sodium thiosulfate or activated carbon.

Points of Application

Selection of application points depend on the purpose of chlorination and the physical layout of the plant. Chlorination practice has a terminology associated with application points.

Plain chlorination is the application of chlorine to an otherwise untreated water supply as it enters the distribution system or the pipe leading to it.

Prechlorination is the addition of chlorine to water **prior** to any other treatment.

Post-chlorination is the addition of chlorine **subsequent** to any other treatment.

Re-chlorination is the application of chlorine to water at one or more points in the distribution system following previous chlorination treatment.

Chlorination Capacity

The amount of chlorine used in water treatment at a plant is usually expressed in terms of pounds per day and chlorine feeders are calibrated in units of pounds per day. The amount of chlorine required for proper disinfection, or other use, depends on the chlorine demand of the water, (expressed in ppm), the flow of water (in mgd), the amount and kind of chlorine residual desired, and the contact time.

Chlorine demand is defined as the difference between the amount of chlorine added and the residual obtained under standard specified conditions. Chlorine demand is determined by standardized techniques as given in the 10th Edition of "Standard Methods for Water and Sewage Analysis." Chlorine demand depends on impurities present in the water, temperature and contact time.

Residual chlorine is defined as the amount of free or combined chlorine remaining after the chlorine demand has been satisfied. It is determined by standardized techniques, using ortho-tolodine or orthe-tolidine-arsenite reagents, or by amperometric titration.

The chlorine dosage required is the sum of the chlorine demand and the chlorine residual desired. It is expressed, usually in pounds per 24 hours and is calculated by multiplying the chlorine demand (in ppm) by the factor 8.34, and by the rate of water flow (in mgd). To choose the proper size chlorine feeder, the maximum rate of flow and the maximum expected chlorine demand are used in the calculation. Normally, it may be expected that the maximum chlorine demand will not be more than 2 ppm, in waters which are not highly polluted.

Chlorine Feeder Control

The feeding of chlorine gas by machines designed for that purpose may be controlled in one of four ways: (1) Manual control, wherein start, stop and rate of feed is set manually; (2) Semi-automatic control wherein the feeder starts or stops automatically with a pump or timer control and operation is at a manually pre-set rate (this system includes "step" operation); (3) Program control wherein the chlorine feed rate is automatically changed throughout the day according to a predetermined schedule; (4) Proportional pacing control wherein the equipment automatically adjusts the chlorine feed rate to provide a constant preestablished dosage regardless of the rate of flow of the water.

Types of Feeders

Chlorine feeder devices may be either vacuum-type, partial vacuum-type, partial vacuum type, pressure type, or pulsating type. Chlorine may be delivered either as a solution or as a direct feed to one or more points of application, (solution feed is most common in water treatment).

The installation of chlorine feed equipment should consider point of application, accessibility of feeder location, space requirement heating facilities and safety conditions.

Treatment

Control of chlorination best accomplished by chlorine residual tests, feed adjustments according to chlorine dosage nomograms, and bacteriological tests for confirmation of disinfection results.

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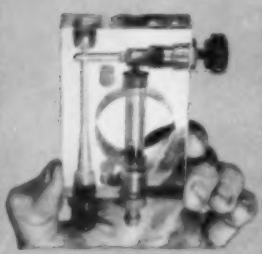
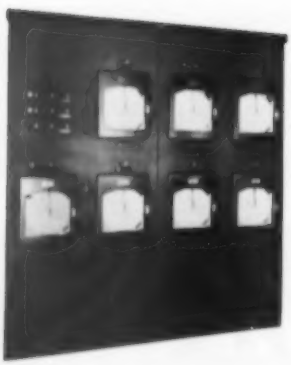


CHEMICAL FEEDING

F&P hypochlorinators, gas chlorinators, and small reagent feeders handle flows from 0.03 gallons of solution per hour up to 8000 pounds of gas chlorine per 24-hour day. Various control instruments may be readily used with dry feeders. F&P feeder systems are ideal for alum, carbon, lime, and soda addition, and for injecting fluoride solutions.



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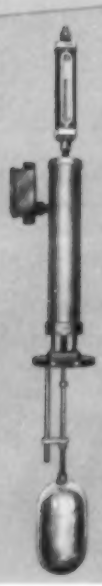

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Instruments for ranges from 0-5 inches to 0-35 feet, available with electric or pneumatic transmitters for remote indication, recording, controlling. F&P Levelrator meters are used in conjunction with Parshall flumes and weirs for flow measurement and/or automatic proportioning of chlorine.

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Standard-size case and miniature case: for transmitting, recording, controlling such measured variables as temperature, pressure, flow, flow ratio, liquid level, etc.

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Chlorination Controls Pipeline Growths*

by GEORGE Y. BLAIR

Asst. Engr., Water-Gas-Sewer Div., Palo Alto, Calif.

IN February 1951 Palo Alto, Calif., began the chlorination of all water entering its distribution system, employing individual chlorination units at each of the city's eight well sites and at two connections with transmission lines from San Francisco. This measure was adopted in response to increasing complaints of "red water" and foul odors, conditions that arose shortly after the introduction of the supplementary supply from San Francisco in 1938 and became progressively worse over the years despite a main-flushing program.

A number of utilities in the California coastal area have been plagued by red water troubles due to *Crenothrix*, a genus of iron bacteria *(1, 2)*. It had been reported that some of the San Francisco transmission lines were infested by this organism. If that were so, the Palo Alto system might also have become infested. Iron bacteria assimilate oxygen and partially oxidized iron, complete the oxidation reaction, and produce red water upon being sloughed off of pipe walls. When such bacterial activity is going on, the water can become so depleted of its dissolved oxygen that anaerobic conditions may result. Such a situation was found to exist in the Palo Alto distribution system, principally in dead ends and other areas of low flow. These so-called zones of degradation were characterized by little or no dissolved oxygen, foul odors, and *Crenothrix* colonies. Tests made by the state health department at the city's request indicated the presence of *Crenothrix* in a majority of the Palo Alto wells, the water supply from San Francisco, and many points in the distribution system itself.

Chlorination Program

It was decided that chlorination was the most economical and practical means of combating the effects of *Crenothrix*. The necessary equipment was purchased and installed in 1950. Before actually starting chlorination, however, exhaustive dissolved-oxygen tests were made, so that the results could be used to measure any subsequent improvement. These tests, approximately 200 of which were carried out in all known areas of degradation throughout the distribution system and at all sources of supply, showed a dissolved-oxygen content ranging from 0 ppm to 4.0 ppm, the average being 1.9 ppm, substantially less than the 6.5-ppm average found at the various points of entry into the system.

Another step taken in advance of chlorination was to enlist the aid of the local newspaper in notifying consumers of the reasons for the program, the results expected, and the tastes and odors that would be present during its early stages. It is believed that this precaution helped greatly to keep the number of initial complaints to a minimum.

The city planned to attempt to maintain, from the start, a 1.0-ppm free chlorine residual in the distribution reservoirs, and at the transmission line connections, in order to hasten the action of the chlorine on the bacterial colonies. It was expected that, as the chlorine passed through the distribution system, its reaction with the bacterial products would cause tastes and odors to become more and more evident. It is worthy of note, however, that, in those areas of the system where the free chlorine residual was on the order of 0.4 ppm, no objectionable tastes or odors occurred, although they were quite prevalent where the residual was less than 0.2 ppm.

Distribution System Flushed

In an effort to carry a 1.0-ppm free chlorine residual throughout the whole distribution system, a new flushing program was undertaken. Systematically covering one area after another, working from the various points of entry into the system toward the extremities, it required approximately 2 weeks to flush out the system completely. This procedure was repeated for a period of 3 months. During the first month of chlorination, great quantities of tubercles and slime organisms were to be found issuing from the fire hydrants when flushed.

In that same month, dissolved-oxygen and free chlorine residual determinations made at selected control points indicated that the anticipated results were being obtained. The average oxygen demand fell from 4.6 ppm to 0.5 ppm. During the early phases, the average free chlorine residual in the system was 0.2 ppm, varying from a maximum of 1.0 ppm in the reservoir effluent to zero in the distribution system extremities. As the flushing program proceeded, the average system residual rose to 0.6 ppm, with 0.2 ppm at the extremities.

Results Achieved

After 3 months red water complaints stopped completely, but some reports of tastes and odors continued to be received, all of them from consumers whose service lines were so infested with *Crenothrix* that the entire free chlorine residual available in the distribution mains was being absorbed. In time this condition cleared up, although occasional taste and odor complaints are still being received. In practically all such instances, it is found that the offense occurs in the morning, after the water has lain in the pipes overnight and all the free chlorine has been consumed. After this water and its chloro products have been expelled from the lines, the tastes and odors vanish, only to recur when consumer use drops off and the free chlorine residual again disappears. It often happens that a service line sample will show no free residual chlorine when the distribution line sample has as much as 0.6 ppm.

The chlorine demand in the system has steadily decreased—except during the spring of 1952—from an initial average of 0.75 ppm to an average of 0.15 ppm in 1953. In the spring of 1952 the demand rose to 0.75 ppm but dropped off within 2 months as a result of additional flushing. This temporary increase was attributed to the fact that, in the summer of 1951, 3 months after chlorination had started, the flushing program was stopped because it was felt that the distribution system had been sufficiently cleaned.

Specific Wells Responsible

Early in the spring of 1952 renewed complaints began to be received regarding red water. As this condition was not accompanied by tastes and odors, it was conjectured that the trouble was not biological in origin but rather an effect of the chemical composition of the water. Further investi-

*Reprinted from *Jour. A.W.W.A.*, Vol. 46, p. 681, by permission of Amer. Water Works Assn.

gation traced the difficulty to three wells with combined iron and manganese contents ranging from 0.3 to 0.5 ppm. The application of chlorine and the increased dissolved-oxygen content of the water brought about the complete oxidation and eventual precipitation of the iron and manganese. Owing to the relatively short reservoir detention period (3-8 hr), precipitation did not occur until the water was in the distribution system. During the winter months, when the water demand and flow velocities were low, the precipitates were deposited in the system extremities and distribution loops. In the spring, as the demand increased and San Francisco water (not used in the winter) was introduced into the mains, distribution flows rose in velocity and, in many instances, changed direction, thereby disturbing the deposits and bringing them up into the moving stream, the inevitable result being red water.

It was found possible to eliminate the problem by flushing the system, concentrating on the areas known to be supplied by the three offending wells. In the spring of 1953 red water complaints were less frequent because the trouble had been anticipated and spot flushing programs were initiated early.

The effectiveness of the chlorination and flushing programs is indicated by the fact that, in the year 1952-53, a total of 152 water quality complaints were received, compared with 1,256 during the year 1950-51. This amounts to a reduction of more than 1,100 in just 2 years.

Conclusions

Experience at Palo Alto shows that:

1. Free residual chlorination is an effective means of combating *Crenothrix* infestation, as evidenced by the improvement in water quality and an 88 per cent reduction in complaints in 2 years.

2. A free chlorine residual can be maintained throughout an extensive distribution system (Palo Alto serves 13,000 consumers through 126 miles of distribution mains).

3. The chlorine demand of the distribution system diminishes with time until a stable point is reached.

4. Even though the extent of *Crenothrix* kill in the distribution mains is satisfactory, tastes and odors may still be present at the consumer's tap, because of the additional time required to effect complete kill in the service lines.

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1. Derby, R. L. Control of Slime Growths in Transmission lines. *Jour. AWWA*, **39**:1107 (Nov. 1947).
2. Wilson, Carl, et al. Control of Growths in California Distribution Systems. *Jour. AWWA*, **42**:849 (Sep. 1950).

R&D

Characteristics of Chlorine

Item	Liquid	Gas
Composition (Formula)	Cl_2	Cl_2
Purity (1)	99.9%	99.9%
Color	Amber	Greenish-yellow
Odor		Pungent-irritating
Density—gm/L—0°C, 760 mm	1468	3.214
—lb/cu ft—0°C, 39 psi	91.64	0.2006
Spec. Grav.—760 mm—Air = 1.0	—	2.486 (2)
Water = 1.0	1.46	—
Vapor Pressure (3) 0°C (32°F)	39	—
20°C (68°F)	82	—
40°C (104°F)	150	—
Boiling Point	−34.0°C (−29.2°F)	—
Solubility—gm/100 ml 10°C (50°F) (4)	—	0.98
20°C (68°F)	—	0.716 (5)
30°C (86°F)	—	0.572
40°C (104°F)	—	0.46

(1) At ordinary temperatures, dry chlorine (liquid or gas) will not corrode steel, copper, or other common metals. In the presence of moisture, chlorine is extremely corrosive.

(2) 1.0 lb of liquid will produce 5 cu ft of gas or one volume of liquid will produce 457 volumes of gas.

(3) This pressure is not affected by volume of liquid, hence chlorine pressure gauges are not indicators of amounts of liquid in container.

(4) Below 9.6°C (49.3°F), chlorine combines with water to form solid chlorine hydrate (chlorine ice), $Cl_2 \cdot 8H_2O$.

(5) Approximately 17 gal of water required to dissolve 1.0 lb of chlorine to form saturated solution. For practical purposes, double this value is used.

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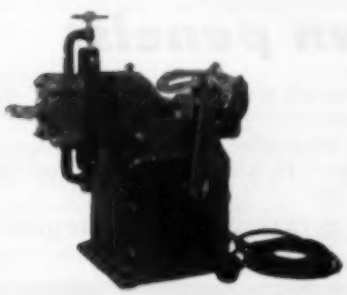
TYPE MASV AUTOMATIC SOLUTION FEED VISIBLE VACUUM CHLORINATOR

Where unusual or extreme fluctuations in water or sewage flow are encountered, the Type MASV meets the chlorination requirements. It embodies all the advantages of automatic proportioning of chlorine feed, and automatic starting and stopping with the outstanding features of the Visible Vacuum Control Chlorinator — rugged construction, simplicity of operation and low maintenance costs.

Type MASV Automatic Visible Vacuum Chlorinator

THE W&T HYPOCHLORINATOR



W&T Hypochlorinator

Chlorination of small water supplies involves problems which the W&T Hypochlorinator is especially designed to meet. This equipment feeds either calcium or sodium hypochlorite in solution form and is furnished in three types.

The Electrically Operated type is particularly useful for small pumped water supplies. Since water pressure furnishes the major part of the operating power, the cost of electricity is but a few cents a day. Automatic Water Operated Hypochlorinators automatically proportion the chlorine solution to the flow of water and are especially adapted to small gravity water supplies with wide variations in flow.

The Belt Driven unit is a sturdy, dependable unit for use where electric power is not available or where operation is to be synchronized with pumping equipment driven by gasoline engine or other similar motive power.

WT SILACTOR ®

The WT Silactor (pronounced SILL-actor) provides a system for the continuous production of activated silica with chlorine. Raw materials—chlorine and sodium silicate—are withdrawn directly from their own containers without handling or dilution. All chlorine used in the WT Silactor is available for the normal functions of chlorine, such as killing bacteria and algae, or for the oxidation of iron, manganese and other oxidizable material.

WT Silactor

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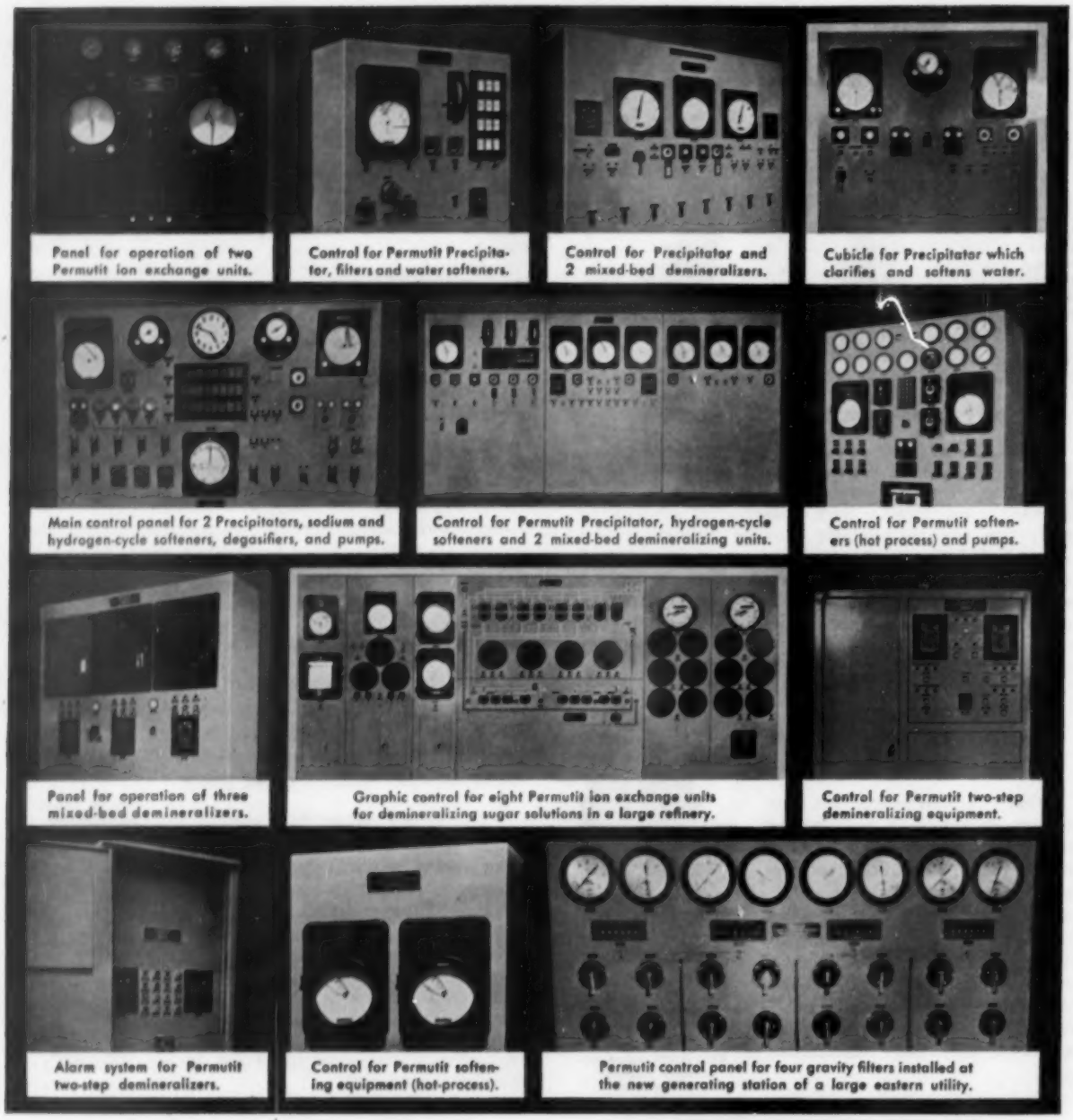
For the application of dry chemicals, Wallace & Tiernan offers a complete line of feeding equipment. The Types MO, MOF and MOI Dry Feeders include such advantages as positive agitation, easy calibration and accurate feed over ranges of from 0.5 to 200 pounds per hour, depending upon the chemical used.

CONVENIENCE

W&T is represented in each of the 39 cities by a service staff prepared to give advice on the proper equipment for any chlorination problem.

Current literature on the many phases of chlorination, ammoniation and dry chemical feeding is available on request.



Panel for operation of two Permutit ion exchange units.

Control for Permutit Precipitator, filters and water softeners.

Control for Precipitator and 2 mixed-bed demineralizers.

Cubicle for Precipitator which clarifies and softens water.

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Control for Permutit Precipitator, hydrogen-cycle softeners and 2 mixed-bed demineralizing units.

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WATER CONDITIONING • ION EXCHANGE

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Water Softening

WATER IS adjudged "hard" or "soft" by the consumer according to whether or not soap lathers freely in it. Hardness is caused, principally, by four chemical compounds in solution: Calcium bicarbonate, magnesium bicarbonate, calcium sulfate and magnesium sulfate. Sometimes calcium or magnesium chloride or nitrate are present as may be iron and manganese. Any and all of these substances cause water to be hard when present. Hard waters not only consume soap and do not lather freely but they deposit scale in boilers, cause soap curds, and produce the well known bath tub ring.

Hard water is found in every state except Washington, Oregon and the Atlantic Coast States. States with extremely hard waters include Illinois, Indiana, Iowa, North and South Dakota, Nebraska, Kansas, Arizona and New Mexico.

Water Softening Processes

Water is softened by removing the calcium and magnesium. This process may be accomplished in two ways. The calcium and magnesium can be precipitated by the addition of lime or lime and soda ash, or the calcium and magnesium can be removed by passing the water over a bed of ion-exchange material which will exchange sodium ions for the calcium and magnesium. In the former process, the total concentration of dissolved chemical salts in the water is reduced. In the latter process the total concentration of salts is not reduced but the chemical salts in the water are changed from calcium and magnesium compounds to sodium compounds.

Lime-Soda Process

The addition of lime to water to soften it has been used for more than 100 years. Adoption of the process grew rapidly after 1903 when the first municipal softening plant was built in Oberlin, Ohio, but the total number of municipal softening plants in the U. S. is less than 1000, but railroads and power plants generally soften their water supplies.

When lime—$Ca(OH)_2$—is added to water containing calcium bicarbonate, all (or practically all) of the calcium, both present and added, is precipitated as insoluble calcium carbonate sludge. If magnesium is present, it is precipitated as magnesium hydroxide. When sulfates or chlorides of calcium and magnesium(that is, non-carbonate hardness) are present, soda ash—Na_2CO_3—is added to produce calcium and magnesium carbonate, and an excess of lime converts the magnesium carbonate to the insoluble hydroxide.

The amounts of lime and soda ash to add are determined by laboratory tests, particularly test for alkalinity and total and non-carbonate hardness. Lime or lime and soda ash are added by dry chemical feeders. Where quicklime is used instead of hydrated lime, a lime feeder and slaker are used to feed the chemical.

An excess of lime must be used to insure a complete precipitation of calcium and magnesium. This produces a free hydroxide alkalinity with a high pH and may effect the taste of the water. Some of the calcium will remain in colloidal condition and precipitate later on filters or in pipe lines. To avoid this difficulty, carbon dioxide is added to the softened water to lower the pH and prevent after precipitation of calcium carbonate. This process is known as recarbonation and has been termed stabilization but the latter term is more often used to signify the use of glassy phosphates to prevent corrosion and red water.

Ion Exchange Process

Early use of the ion-exchange process of water softening was confined to natural zeolites (greensand) and to household softeners. Modern synthetic ion-exchange resins have a large capacity to soften water and are easily regenerated by salt brine. Large installations for municipal water softening are now in use and operate almost automatically in the softening and regeneration cycle.

Economic Aspects

Water in hard water areas is softened to reduce soap consumption, to reduce bad effect on clothes washed in it, to reduce bad effects on plumbing, heating systems, boiler tubes and shells and to improve its acceptability for industrial process use.

It has been shown that it is cheaper to pay a reasonable charge for centralized softening than to accept a hard water supply, a part of which must be softened in the home. Softening water with soap (for that is what happens in order to produce a lather) is expensive. Studies have shown that soap wastage will be greater in dollar value per capita than the cost per capita of softening the entire supply.

With the advent of synthetic detergents, termed syndets, the argument for softening to save soap is lessened because syndets will perform in hard water with no loss of washing power. The softening of water for boiler use, power plants and process waters remains a necessary process. The use of syndets however may lessen public pressure to install water softening plants where they do not now exist.

In 1951, L. R. Howson, Cons. Engr. of Chicago wrote that "Most public water supplies with a hardness of 125 ppm or more will eventually be softened not only because the cost of softening is outweighed by the savings which result from the softening, but also because water softening makes a community a better place to live."

In 1953, T. E. Larson, Chief Chemist, Ill. State Water Survey Div. expressed the opinion that further observation would be needed before it could be determined just what effect the use of syndets would have on water softening practices both in municipal plants and in home softeness.

In 1951 syndets accounted for 35 per cent of the detergent market; in 1952, 45.7 per cent; in 1953, 54 per cent; and in 1954, 59.1 per cent. Syndet manufacturers expect to capture 75 per cent of the total detergent market in the next several years. This growth, plus the development of new detergents may affect the public attitude toward softening.

It seems highly unlikely however that present municipal water softening plants will be discontinued in the foreseeable future and certainly water softening in industry will continue to be an essential process.

Lime and Lime Slaking

By H. E. LORDLEY
Asst. Director, Dept. of Public Utilities, Richmond, Va.

LIME is one of the oldest chemicals known to civilization, yet the efficient utilization of this important chemical is impeded by lack of complete information concerning its physical and chemical properties. Since lime is used in such large quantities for softening and corrosion control in the water works field, it is amazing that so little information is to be found in water works literature on the subject of lime and lime slaking.

There Is Lime and Lime

Limestone, which is the source of the calcium oxide, will vary in physical and chemical properties in different parts of the country. Some limestone is high in magnesium which is objectionable for use in water purification plants, yet suitable for other chemical processes. Other sources are high in iron and silica, so it is well to study an analysis of the raw stone before buying lime for the water plant. At the lime plant, in the first step of processing the rock for calcining, a superoir finished product results if mud, sand, and other impurities are removed before burning. In the actual calcining step, the manufacturer can control both the physical and chemical properties of the lime, either by the type of kiln or the method of firing. Therefore, we get much lime that is either under-burned or over-burned by lack of control of the process at the kiln.

Take, for example, the old style vertical kiln using coal as a source of heat without modern control equipment, we find that the lime thus burned will slake very slowly. On the other hand, the modern controlled rotary kiln produces lime that will slake so rapidly that it actually explodes in the slaker. The author recalls an amusing incident at the Richmond Filter plant on changing from a vertical kiln to a rotary kiln lime. The operator frantically called to report that the lime slaker was out of order and making a terrible rumble in the slaking chamber. On investigation, the new rotary kiln lime was producing miniature explositions that sounded like a loose agitator blade. Also common to the old style vertical kiln is the large percentage of core as compared to practically core-free lime from the rotary kiln. So we see that all lime is not the same from every lime plant and the water works executive must choose the source of lime carefully if highest efficiency is to result.

As to Lime Properties

After the lime leaves the kiln it must be graded as to size. Quicklime can be furnished in sizes varying from a fine pulverized product, which will pass a 200 mesh screen, to a pebble lime of two inch size. In determining the proper size to use in the plant, the operator must remember that the pulverized lime offers both a dust problem and a feeding problem due to arching in the hopper. Dust can be controlled by proper ventilating system, but archhing is just a universal worry. Arching can be partly corrected by design of light weight hoppers having a bottom slope of not less than 60° from the horizontal. "Syntron" vibrators on the side of the hopper will further reduce arching, but the best answer is the use of pebble lime of size from ¼ inch to ¾ inch, provided suitable feeding and slaking equipment is available. Dust is reduced, arching in hopper is eliminated, and air-slaking of lime in storage is not as rapid with pebble lime as with the pulverized lime. Another physical property of interest is the color of the lime; white, gray, black, blue, etc. All are high in calcium oxide, and color is not a criterion of a good lime. The chemical properties and specifications are easy to determine in the laboratory. The lime should contain not less tran 90 per cent CaO, have a low magnesia, silica, and iron content, and be free of arsenic.

In many plants today, calcium hydroxide (hydrated lime) is preferred to calcium oxide, due largely to lack of information and equipment for slaking the oxide. The lime manufacturer is anxious to dispose of calcium hydroxide, since all fines from calcium oxide are converted into calcium hydroxide at the lime plant. The water works executive must remember that he pays for slaking process plus freight on water in hauling hydrated lime in preference to burned lime.

Economic Considerations

TABLE I

	Typical Calcium Oxide Lime	Typical Calcium Hydroxide Lime
Insoluble Residue	1.57	.37
R_2O_3	.48	.52
Loss on Ignition	1.34	2.19
Magnesium oxide	1.26	.50
Calcium oxide	95.33	92.00*
CaO Equivalents	96.59	70.00
Cost Price Del./Ton	$11.00	$10.00
Cost Price per ton CaO	$11.38	$14.28

*Calcium Hydroxide—$Ca(OH)_2$ or $CaO + H_2O$.

In Table No. 1, a typical analysis and price of calcium hydroxide as compared to calcium oxide shows the economic status of the two types of lime. In buying a typical pebble calcium oxide in place of calcium hydroxide, a net saving of $2.90 per ton of CaO equivalents is realized, plus higher operating efficiency. In actual plant operation the saving will be greater, since the theoretical ratio of one part CaO to 1.32 parts $Ca(OH)_2$ approaches a practical operating ratio of 1 part CaO to 1.5 parts $Ca(OH)_2$.

Another way to save money in buying quicklime is in the size of the lime. A pulverized calcium oxide (passing 200 mesh) is more costly than a standard pebble or cracked lime. The manufacturer must charge for the expensive process of pulverizing and will raise the price of calcium oxide from $11.00/ton to approximately $13.00/ton for the pulverized product. Also for large plants, the lime shipped in 15 ton cars costs more than in 25 ton cars, due to the freight rates.

With the money that can be saved by shifting from calcium hydroxide to pebble calcium oxide, an excellent feeder and slaker can be purchased and the lime treatment will become a controlled process rather than the usual "hit or miss" process. The operator should investigate and experiment with different types of lime to find the one best suited to his own plant and local conditions.

Lime Slaking Equipment and Its Operation

The operation of the slaker is not easy. Like a man learning to ride a bicycle, the problem looks simple yet requires initial research and a few hard knocks before the art is mastered.

First, and most essential, is an efficient dry-feeder. In the Richmond Filter Plant, an Omega lime feeder delivers the lime to the slaking vat at an astoundingly accurate rate. The feeder is a gravimetric batch type having a maximum capacity of 175 pound/hour and a minimum capacity of 1.75-pound/hour. The feeder has a 1,000 pound capacity, and properly designed hopper equipped with an agitator and mounted on a sensitive beam scale. The adjusting mechanism for changing the rate of feed is located in a compact unit with an alarm to indicate any trouble in feeding, such as an empty hopper or failure of material to leave the hopper. The lime feed is controlled by the vibrating plate at the bottom of the hopper. The pebble lime of size not exceeding ¾ inch size falls off the vibrating plate directly into a compact Omega Slaker located on the same floor with the feeder in a floor space of only 54 inch by 84 inch for both feeder and slaker. The unit is equipped with a water operated vapor removal system to collect dust and steam from the slaker. The water from this unit is not wasted, but is used as make-up water for the slaker or in conveying the lime to the

point of application. The slaker has a minimum retention period of 30 minutes at the maximum rate of feed and is agitated with a motor driven impeller so adjusted to give proper circulation in the chamber.

Temperature Control Important

The optimum temperature for slaking will vary both with the type of lime and the retention period in the slaker. The most efficient slaker temperature range is between 150° F. and 180° F.; above 180° F. the steam and vapor will overload the vapor removal equipment and cause corrosion of the slaker and feeder. In the Richmond plant, the optimum temperature is 160° F. using a pebble lime having a 96 per cent CaO content. In order to maintain this temperature in the shaker, with our incoming water varying between 33° F. and 85° F., an electric water heater of three No. M-240, 4,000 watt Chronolox immersion heaters was purchased for the job. The heaters are equipped with three-way switches for seasonal control and thermostats on each unit to supply makeup water at a uniform temperature regardless of the temperature of the incoming water. The heat of hydration of calcium oxide is 273 calories per gram. However, in slaking small quantities of lime some of this heat is lost and must be supplemented by heat from the make-up water.

Proper Water Ratio

In slaking lime, too little water gives a heavy slurry that is too thick to be agitated properly by the impeller, yet an excess of water increases the expense of heating make-up water and will dilute the lime so that maximum retention time in the slaker is materially reduced. Different brands of lime require variable quantities of water, but a slurry of the proper viscosity is usually obtained by a ratio range of 1 pound lime to 3 pounds water to a ratio of 1:4¼. After a series of experiments at the Richmond plant, the ratio of 1:4 was adopted and gives excellent operating results.

To control the ratio, a standard water meter is connected in the supply line to the heater. The meter was geared so that the lowest dial actually reads 3 times the amount of water passing through the meter. For example, one cubic foot of water passing through the meter indicated three cubic feet on the dial. This method was devised to afford the operator a chance to check the water flow at low rates much more readily than with the regular meter dial. After checking the flow, the operator refers to a chart (see Table 2) showing the meter reading corresponding to each rate of lime feed for a ratio of 1:4, adjustment being made by the needle control valve if necessary. Example: Feed 50 lbs./hr. of lime. Requires for ratio 1:4, 50 × 4 or 200 lbs./hr. of water equals

$$\frac{200}{62.4} = 3.2 \text{ cu. ft. per hour of water.}$$

On special dial, this reads 3.2 × 3 or 9.6. On the chart opposite the rate of 50 lbs./hr. is the value 9.6 which should be the reading of the meter for one hour. The operator adjusts the valve to get this reading.

The lime after slaking is diluted with water from the vapor removal unit and flows over a weir into the outlet line. Some lime has considerable core so that the machine is designed for core removal, without stopping the slaker operation. The core is removed to a chamber to be washed to recover any calcium hydroxide on the surface and is then dumped into a trash can under the slaker. Tests are being run on the amount of unslaked lime in the sample collected at the effluent of the slaker but are not complete enough at present to report in this paper.

TABLE II

Water Meter Reading vs. Dial Setting for Optimum Ratio one lime to four water.

Pounds/hr. Lime	Dial Setting	Meter Reading (Cu. ft.*)
1.75	1	.3
8.75	5	1.6
17.50	10	3.4
26.25	15	5.0
35.00	20	6.7
43.75	25	8.4
52.50	30	10.0
61.25	35	11.7
70.00	40	13.5
78.75	45	15.1
87.50	50	16.7
96.25	55	18.4

*Special Meter Dial. Indicates three times actual flow.

Piping Lime Suspensions

No other problem seems more perplexing than that of transporting the lime to the point of application 300 feet or 400 feet from the slaker. If duplicate lines are available, one line can be cleaned with a chlorine solution while the other line is in service. However, caution must be observed to prevent the chlorine from actually attacking the iron pipe. Recently suggested is the use of "Calgon" to keep the lines free of incrustants but so far little work has been reported on this method. Many plants use rubber hose and clean the line by beating or shaking the hose. The author has found that the open trough is the simplest method of delivering the lime, provided the necessary fall between the machine and point of application can be obtained.

pH Control Simplified

So accurate is the control of pH with the new Omega slaker that in the Richmond plant we can hold a constant pH of 8.7 in our finished water. It is important to note in Table No. 3 that prior to the installation of the slaker, we had trouble in our distribution system with a decided drop in pH. Now with the present slaker we have only a slight drop and a corresponding decrease of iron in the dead-ends. We can only explain this by the fact that the controlled slaking is productive of a more highly peptized lime suspension—more nearly a colloidal suspension.

TABLE III

Station No. 34*
Location—Broad Rock Road

	Before Slaker Installation 1938	After Slaker Installation 1940
Res. Cl_2	.00	.00
Turb.	6.0	.80
Color	40	10
Alk. (M.)	23	36
Alk. (Phen.)	0	4.5
CO_2	0	0
pH	8.1	8.6
Fe_2O_3	4.0	.40

*This station is located near a dead-end.

It is hoped that water works men will study lime treatment and get more lime per dollar. Remember that often obsolete equipment can be scrapped and new equipment purchased with the saving. so why not have a modern plant at no extra cost?

Recarbonation With Liquid Carbon Dioxide*

By ARTHUR F. MELLEN

Supt. of Water Treatment, Water Works Dept., Minneapolis, Minn.

WATER softening by the lime process has been practiced for many years, but the product originally was not satisfactory for either domestic or industrial use because it was super-saturated with normal carbonates of calcium and magnesium. Such water tended to cause incrustation in flumes, pipes and filters at the treatment plants, as well as in mains, service lines and meters, and was particularly objectionable in hot-water lines.

Lime softening upsets the chemical balance of natural water, which presents a very definite problem to the plant operator. If a corrective treatment results in a pH that is too high, incrustation may occur, while if the pH is too low, corrosion may result. The optimum pH zone may be very limited.

Attempts were made many years ago to stabilize softened water with carbon dioxide, but the process was unattractive because of producer and application grid troubles.

The conventional producer plant usually consists of a unit for the burning of coke, gas, oil or powdered anthracite coal, although stack gases, such as those from a pumping station, are often used. These gases are scrubbed in order to free them from corrosive components and are then dried, compressed and delivered to the point of application.

Mechanical difficulties with the compressor often give a great deal of trouble, resulting in frequent interruptions of service because of needed repairs and requiring relatively large amounts of time and money for maintenance. Undesirable irregularities in the quality of the carbon dioxide produced, and, hence, in the treatment of the water, may also occur.

In the modern carbon dioxide plant, the compressor is the first instead of, as formerly, the last unit in the producer line. Since the compressor handles only clean air and the entire system is under pressure, combustion is complete, making scrubbing and drying unnecessary. This arrangement considerably simplifies the problem of carbon dioxide production.

The conventional softening plant requires a relatively large recarbonation basin area. The gas produced has a carbon dioxide value of approximately 13 per cent, the balance being principally atmospheric nitrogen. The distribution header in such a basin is usually fitted with ¾-in. laterals of galvanized steel or brass, spaced on 1-ft. centers and drilled on 1-ft. centers with ⅛-in. holes, pointed downward. The size of these orifices is critical. If they are too wide, the gas bubbles will be large and may not completely react before reaching the surface of the water, thus resulting in a loss. On the other hand, if they are too small, the tendency is to clog rapidly with incrustation.

Dry-Ice Installations

Dry ice is also a source of carbon dioxide for stabilization. In January, 1946, having made lease arrangements with the Liquid Carbonic Corp., the Minneapolis Water Dept. put into service at the Fridley Filtration Plant two 4-ton dry-ice converters with the necessary evaporators, controls and meters. Experimental work was carried on during the next 1½ years, although not continuously. At the end of that time it appeared that the use of 100 per cent carbon dioxide was attractive but that the liquid form would be preferred to dry ice for an installation of the size required.

Quite a number of dry-ice installations have been made in recent years in small softening plants. An interesting description of such a plant at Wyoming, Ohio, was given in a recent article by Fred G. Gedge (1).

An important feature affecting the economical use of dry ice is the distance from the source of supply. Since it is very expensive to provide storage facilities because of the nature of the material, softening plants are likely to be dependent on very frequent deliveries from nearby sources. Consequently, manpower difficulties are involved, particularly during periods of heavy demand, weekends and so forth.

Liquid Carbon Dioxide

The first experimental use of liquid carbon dioxide was made by the Cardox Corp. of Chicago at the softening plant at Lansing, Mich., in December, 1945, where a 5-ton transport truck was used as the source of supply. The trial runs were satisfactory but the procedure was not continued because the distance from the source made truck deliveries very expensive, and the cost of storage was too great to permit buying the liquid in tank car lots.

In April, 1946, the Cardox Corp. having provided a temporary control panel, Minneapolis experimented with the use of liquid carbon dioxide for about four weeks, during which time three tank cars were used as the source of supply. The results were quite satisfactory.

The first permanent installation was made by the Cardox Corp. at the Minneapolis softening plant in February, 1947, and has been in continuous use since that time. The second installation was at the new South Dist. Filtration Plant in Chicago.

Liquid carbon dioxide is shipped in tank cars containing approximately 48,000 lb. of liquid and gas. The cars, in general, resemble those used for gasoline or oil, except that they have especially thick steel shells and unusual safety devices which are required by the Interstate Commerce Commission. There are two popoff valves which release at approximately 325 and 375 psi. It is not possible to make such a shipment without very considerable vapor loss, except at midwinter temperatures. These losses are high during the summer, but payment is made on the basis of car weights at Minneapolis.

Duplicate unloading pumps deliver the liquid from tank cars to storage tanks. Credit is given for 2,700 lb. of carbon dioxide in the returned car. The cost of storage tanks of such capacity as would compare with the reserve inventory of other chemicals (approximately 30 days' supply) appeared to be prohibitive. Although the department prefers to use carbon dioxide exclusively, filter alum may be employed for acidification in the event of a shortage, being sure that the pH is kept low enough to avoid the presence of soluble aluminum compounds. The storage facilities consist of two tanks holding 40 tons each, which are insulated with 6 in. of pressed cork. The vapor pressure in the storage tanks ranges from 270 to 290 psi. Each tank is provided with a unit which converts the liquid into vapor. These units consist of the necessary electrical and thermostatic controls with vaporizing cylinders having 3—5-kw. heating elements. They have a maximum capacity of about 11,000 lb. per day.

Each storage tank has its own refrigerating system, which automatically functions when the vapor pressure becomes too high. When sufficient vapor has been converted to liquid and the pressure is reduced, the refrigerating system automatically cuts out.

The gas is withdrawn from the storage tank at a temperature of approximately 0°F. and passes to the control board, where it is preheated in vapor heaters so that, when it passes through the pressure-reducing valve, the temperature of the metered vapor is 50°F. and the pressure is 20 psi. The vapor is proportioned as required by three rotameters and passes into two header systems which convey the gas into two sets of diffusers, one for each of the twin recarbonation chambers. Each bank of diffusers has nine units, consisting of 1½-in. cotton fabric hose similar in appearance to that of a fire hose without the rubber liner. This hose is specially manufactured for controlled porosity and is treated against damage by molds. By breaking unions in the pipe on each side of the chamber, the diffuser units may easily be raised for inspection or repair.

The use of these diffusers has a great advantage over the conventional orifice type, principally because they occupy much less space, are much cheaper to install and can be inspected or repaired without dewatering the chambers, as is necessary in the conventional type.

Of course, it is evident that the diffuser area required when 100 per cent carbon dioxide is used is proportionally less than if a 13 per cent producer gas is employed.

Commercial production of dry ice and liquid carbon dioxide is increasing greatly each year because of refrigeration and soft-drink requirements. Production and shipping problems are being worked out so that these products will be available not only in large industrial centers, but also at many other strategic points, making tank truck service feasible.

It seems safe to forecast that the trend will be increasingly away from carbon dioxide produced at the softening plant and toward the use of dry ice or liquid carbon dioxide where frequent deliveries of small shipments can be reliably made.

Reference

1. Gedge, Fred G. Use of Commercial Carbon Dioxide in Lime Softening. Jour. A.W.W.A., 41:159 (Feb. 1949).

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Iron and Manganese Removal

By ESKEL NORDELL
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IRON and manganese can be considered two of the most troublesome elements to be found in natural water supplies. As to the troubles caused by these elements, they are legion. To mention just a few: in the household—procelain fixtures, glassware, laundered materials, etc., develop unsightly stains which are very difficult to remove, and tea and coffee made with such waters become muddy-looking. unpalatable beverages. In the industries, even more serious difficulties are encountered—cotton, wool, and other textiles cannot be processed in such waters; rayon manufacture is impossible; dyeing is uneven and spotty; tanning is difficult; beverages develop troublesome and unsightly precipitates; quality pulp and paper production is impossible; etc.

In addition to these various difficulties, iron and manganese tend to favor the growth of iron and manganese micro-organisms popularly lumped together under the designation "crenothrix." These iron and manganese crenothrix growths clog pipe lines, meters, fixtures, nozzles, recirculating systems; and other water-handling equipment, cutting down flow rates and frequently breaking loose in large, clogging masses which, as they decompose, impart objectionable tastes and odors to the water.

The commonest form in which these metals occur is in the reduced state, as ferrous bicarbonate or manganous bicarbonate. These divalent bicarbonates are colorless compounds which exist only in solution and are most commonly found in deep well waters or spring waters. They can also, occur, in cases of iron or manganese pickup, when an unaerated water is pumped through distribution systems containing the insoluble, higher oxides or hydrated oxides. Under such conditions, a portion of these deposits may be reduced to the divalent form, which then goes into solution.

The second commonest form in which iron and manganese occur is in an organic or colloidal form, usually in surface waters and lower strata water in deep reservoirs, sometimes in shallow well waters and occasionally in deep well waters. Almost invariably, these waters have a rather high color, due to the organic matter present.

A third form is as the divalent sulfates—ferrous sulfate or manganous sulfate, but these are found only in acid waters such as (1) acid mine waters, (2) acid well or spring waters in the neighborhood of mines or contaminated by trade wastes, or (3) acid surface waters which similarly have been contaminated by acid mine waters or trade wastes.

A fourth form, of secondary origin and which applies almost entirely to iron, is as the suspended, insoluble higher oxide formed by corrosion of the distribution system or by aeration of a water containing ferrous bicarbonate, either of which causes the familiar "Red Water." In the absence of oxygen and presence of sulphides foul smelling "Black Water" issues from fire-haydrants or dead-end blow-offs.

Ferrous Bicarbonate—Manganous Bicarbonate

Iron or manganese, when present as the divalent carbonates, may be removed by one of four processes:

(1) Aeration, followed by settling, and filtration
(2) Oxidation with Chlorine, followed by settling and filtration
(3) Cation Exchange
(4) Manganese Zeolite

Aeration, Settling, and Filtration:

Both iron and manganese may be removed by aeration, settling and filtration but as manganese requires different conditions for its oxidation, the removal of ferrous bicarbonate will be considered first. *Ferrous* bicarbonate has a very appreciable solubility which varies somewhat according to the amount of free carbon dioxide present, while *ferric* hydroxide has a solubility which is so low that it is negligible. Therefore, on oxidizing ferrous bicarbonate to ferric hydroxide, the iron content of the water will be precipitated in a practically insoluble form. The oxidation is rapid and complete at pH values of 7.0 or over. At somewhat lower pH values, the oxidation proceeds at a much slower

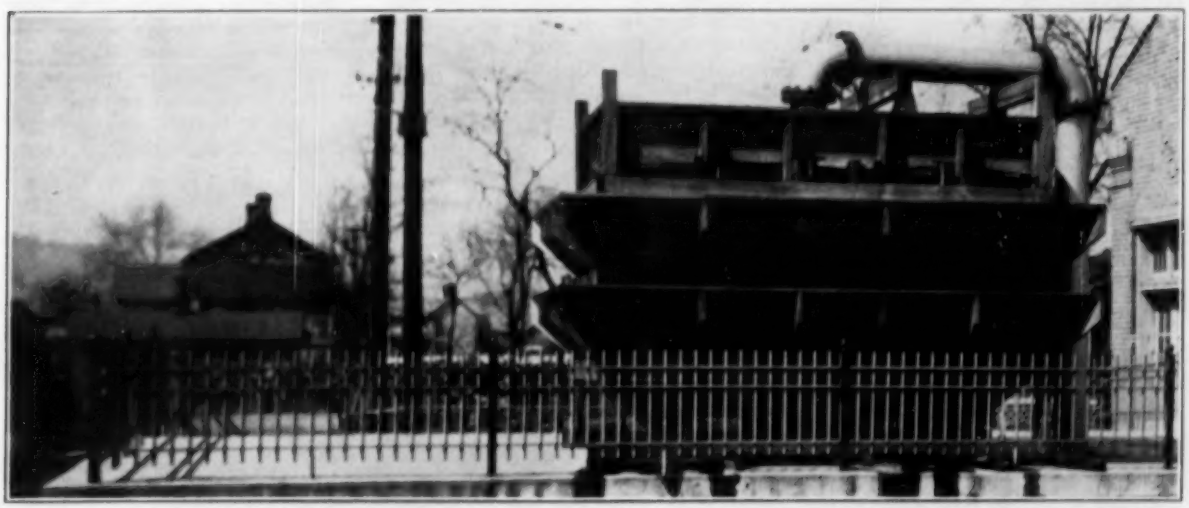

Fig. 1—COKE TRAY aerator preceding manganese zeolite filters and zeolite softeners, Coraopolis, Pa.

Fig. 2—WOOD SLAT TRAY aerator for iron removal on roof preceding filtration, and zeolite softeners, Genoa, Ohio.

rate, so if the pH value of the water is below 7.0, it is advisable to raise it in order to assure complete oxidation and removal of the iron. This effect of pH on the speed of the reaction is clearly shown in the following table of tests with detention periods up to 60 minutes following aeration:

As to the type of aerator employed, probably the most widely used type is the coke tray aerator. Wood slat tray aerators are also used and so are forced draft aerators. It is the usual practice to provide a catch basin or settling basin under or alongside the aerator with a nominal detention period of usually one-half hour or more. Occasionally, when waters have a favorable pH value, this detention period may be as little as 15 minutes. On the other hand, if the iron content is high, then it is advisable to remove the bulk of it by settling, in which case the basin should have a detention period of at least one hour.

From the catch basin or settling basin, the settled water is then passed through sand or Anthrafilt filters. The filters employed may be either of the pressure type or of the gravity type. The removal of iron by this process is very complete and the filter effluent will have an iron content of not more than 0.1 ppm.

If the iron content of the raw water is not above 1.0 ppm, settling before filtration is often dispensed with and, if the pH value is 7.0 or above, then pressure aeration, instead of open aeration, may be employed. In such cases, in order to avoid getting the water so saturated with air that it would spatter when drawn, only a portion of the water is by-passed through the pressure aerator tank and this flow is then mixed with the main flow of water. If the water, for instance, is under a pressure of 60 psig., then not over 20% need be passed through the pressure aerator tank.

Unlike ferrous bicarbonate, which requires a pH value of only 7.0 or slightly over for its oxidation, manganous bicarbonate requires a pH above 10.0 unless "ripened filters" are used. If ripened filters are employed, then a pH of 8.5 to 9.0 is sufficient.

The term "ripened filters" dates back to the rather early days of manganese removal when it was noticed that when a manganese removal plant of the aeration, settling and filtration type was first put in action, apparently little or no removal of manganese occurred for the first couple of days or so and then rather rapidly the plant began to function correctly and removed the managanese. This was due to a slight coating of the higher oxides of manganese on the granules of the filter bed which seems to serve as a catalyst in oxidizing and removing the manganese from the aerated water. One bad feature of the "ripened filters" is that in time, the coatings on the filter media tend to "shell off" and contaminate the effluent. To a great extent, this tendency can be overcome by occasionally dissolving and cleaning off the old coatings before they become too thick and then "ripening" the cleaned media before returning the filter to use.

Table II shows the effect of pH in oxidizing manganous bicarbonate when no catalyst (or "ripened" filter) was employed.

While Table II shows that a pH of 10.3 was required for complete oxidation of the manganese when no catalyst was employed, Table III shows that a pH of 8.5 was sufficient when a catalyst was present. In this case, the catalyst was stirred with the water which afforded an intimate contact similar to that of a ripened filter.

The coke tray type aerator is shown in Fig. 1 and wood slat tray type aerators are shown in Fig. 2. In the first two, iron is removed by aeration and filtration before softening by zeolite to the required degree. In the third, both iron and manganese

Table I

EFFECT OF pH ON THE OXIDATION OF FERROUS IRON BY DISSOLVED AIR

Raw Water		Iron in Aerated and Filtered Water (ppm)		
pH	Iron (ppm.)	(15 min.)	30 min.)	(60 min.)
5.0	10.0	9.0	—	7.5
5.5	10.0	5.5	4.6	4.0
5.95	10.0	5.0	4.0	3.5
6.15	10.0	4.4	3.5	2.5
6.5	10.0	2.8	1.8	0.3
6.65	10.0	0.7	0.2	0.1
6.8	10.0	0.2	0.1	<0.1
7.0	10.0	0.1	<0.1	<0.1
7.45	10.0	0.1	<0.1	<0.1
8.05	10.0	<0.1	<0.1	<0.1

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Table II

EFFECT OF pH ON THE OXIDATION OF MANGANOUS MANGANESE BY DISSOLVED AIR, WITHOUT STIRRING

Raw Water		Manganese in Aerated and Filtered Water (ppm)		
pH	Manganese (ppm.)	(15 min.)	(30 min.)	(60 min.)
8.5	10.0	—	—	10.0
9.0	10.0	—	—	9.0
9.3	10.0	8.3	8.0	7.5
9.5	10.0	7.5	5.0	3.2
9.7	10.0	3.0	1.3	0.9
9.95	10.0	0.9	0.7	0.6
10.3	10.0	<0.02	<0.02	<0.02

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are removed by aeration, chemical softening, settling and filtration.

Oxidation by Chlorine, Settling & Filtration:

Ferrous bircarbonate may be completely oxidized by chlorine at pH values as low as 5.0. While more expensive than aeration, it may be used for removing iron from waters as low as 5. pH value. Chlorine is of little value, however, in the oxidation of manganese, unless ripened filters are employed, for otherwise a pH practically as high as for oxidation by air is required. In some experiments which I made on this, a pH of 10.0 was necessary for complete oxidation and satisfactory settling.

Both metals may be oxidized by potassium permanganate, but since this chemical is rather expensive (over 25c per pound) it has only limited applications and then only for rather small concentrations of either metal. As with the aerating processes, final removal of the higher oxides is effected by (1) settling and filtration or (2) by filtration alone if the iron or manganese content of the raw water is low.

Table III

Catalytic Effect of 1 Gram per Liter of Previously Aerated and Precipitated Manganic Hydroxide, with Stirring, on the Oxidation of Manganous Manganese at Various pH Values

Raw Water + Catalyst		Manganese in Aerated and Filtered Water (ppm)		
pH	Manganese (ppm.)	(15 min.)	(30 min.)	(60 min.)
7.5	10.0	—	—	3.0
8.0	10.0	—	—	0.3
8.5	10.0	<0.1	<0.1	<0.1
9.0	10.0	<0.1	<0.1	<0.1

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Cation Exchange:

Iron or manganese in the form of the soluble, divalent bicarbonates, may be removed simultaneously with the hardness by the familiar Sodium Cation Exchange or Zeolite process. In this, the iron is taken up by the zeolite which gives up an equivalent amount of sodium in exchange for it. The zeolites which are used for this purpose are either of the greensand, carbonaceous or synthetic resin type. It is also the usual practice to limit the application of the cation exchange process to waters having not more than 1 ppm. of iron or manganese to each 2 gpg of hardness, up to a maximum of not over 10 ppm. In other words, with a water containing 10 gpg of hardness, 5 ppm of iron or manganese would be the specified maximum, while with waters having 20 or more gpg of hardness, 10 ppm of iron on manganese would be the specified maximum.

Regarding the completeness of removal of iron and/or manganese by this method, the effluent usually will not contain more than 0.1 ppm of iron or manganese. The capacity of the Zeolite for removal of these metals extends beyond the point at which zero hardness water is produced. In other words, the softener can be overrun a certain amount and still produce an iron manganese free water. This overrun or so-called "salt starvation" method has been used to a certain extent in softening municipal water supplies where the hardness was to be reduced to 5 gpg. In such cases, usually four softeners were employed and the softening runs were staggered at timed intervals so that while one was on the overrun, the other three would still be on the soft-

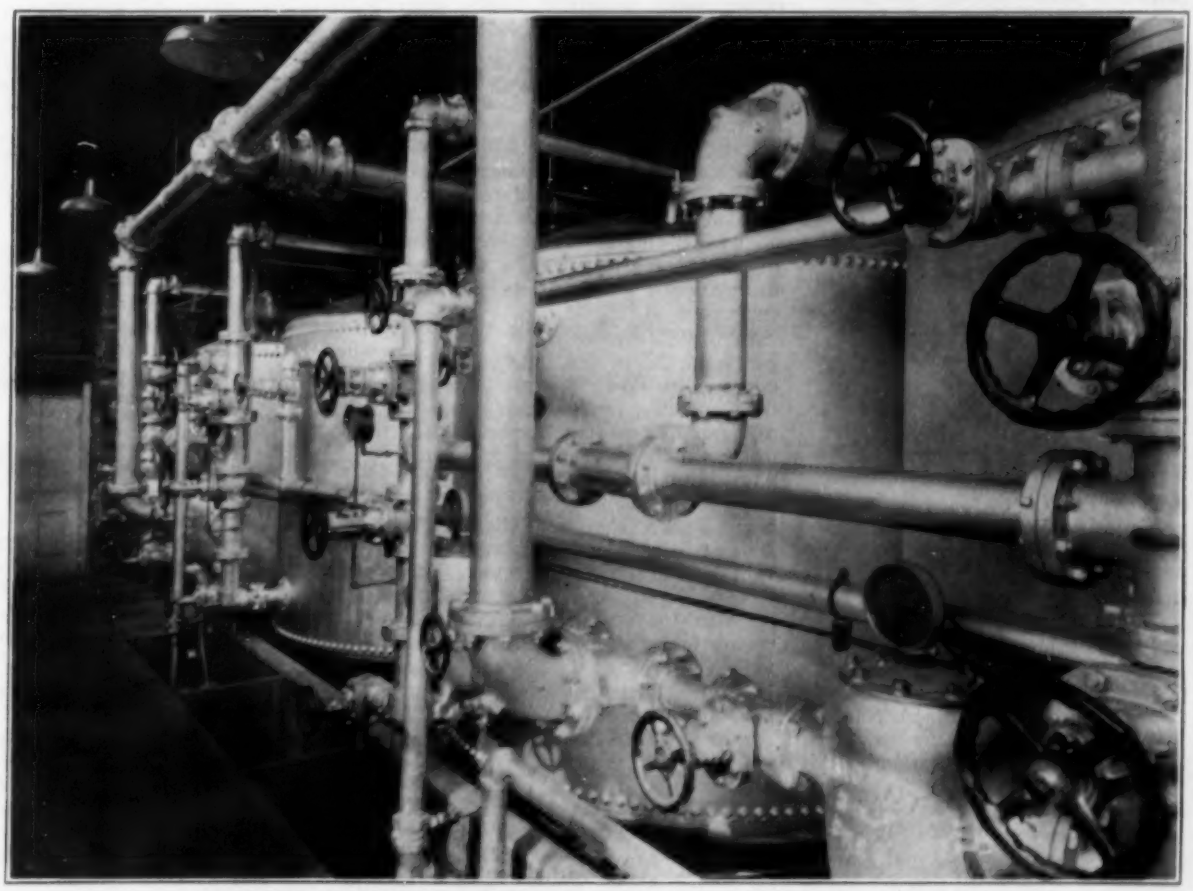

Fig. 3—ZEOLITE UNITS for combination iron and hardness removal at Wapakoneta, Ohio.

ening run. Fig. 3 illustrates a 4-unit iron removal and softening plant of this type.

This method of operation, however, does not result in a mixed effluent of unvarying hardness and it has been largely superceded by another method in which one portion of the water is softened to zero hardness and the iron or manganese simultaneously removed by cation exchange while another portion of the water is treated to remove these metals but not to soften the water. For instance, in one municipality which has a deep well water containing 1 ppm of iron and 20 gpg of hardness, three-fourths of the flow is passed through 5 zeolite water softener units which remove both the hardness and the iron. The other one-fourth is passed through 2 manganese Zeolite filters which remove the iron but not the hardness, after which the two flows join through a mixing valve to produce an iron-free (0.1 ppm or less) 5 gpg hardness water.

It is important in applying this zeolite process of iron removal to keep the entering raw water from contact with air. The reason for that is that if air comes in contact with the water before it passes through the zeolite bed, some of the iron would be precipitated and filtered out by the zeolite, and the zeolite softener is not designed to act as a filter. In other words, a filter would be operated at a rate of 2 to 3 gpm. per sq. foot and would be backwashed at rates of 10 gpm. per sq. foot or over. Zeolite softeners, on the other hand, are designed to operate at flow rates of from 5 to 8 gpm. per sq. foot and are backwashed at rates of from 5 to 6 gpm. per sq. foot.

Obviously, the iron and/or manganese may also be removed from all of the water, by aeration and filtration, before softening it to whatever degree is required. In Fig. 2, all of the water is aerated, settled and filtered before softening to the required degree with zeolite.

Cation exchangers, operating on the hydrogen (acid) cycle, will also remove iron or manganese, exchanging hydrogen for them. As these, however, are very rarely used in municipal water treatment plants, there is no need of detailing their operation.

MANGANESE ZEOLITE:

The Manganese Zeolite process is of rather limited application, but is of value in cases where the iron or manganese content is low and it is desirable to treat the water under pressure. For industrial and municipal use, it is the usual practice not to treat waters by this method unless the iron or manganese content is one ppm or less. For household use or for rather small industrial plants, this method may be used with waters containing up to 10 ppm of iron or manganese.

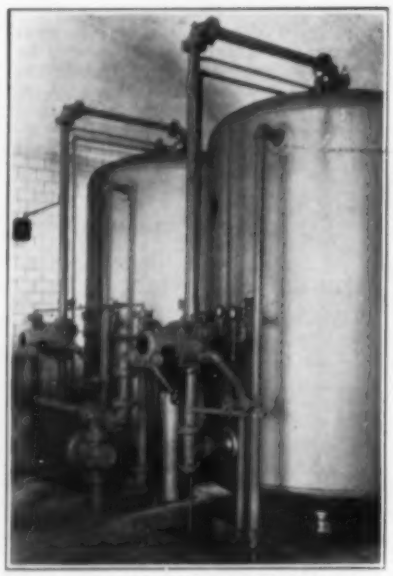

Fig. 4—MANGANESE ZEOLITE filters at East Lansing, Mich., remove iron from 25% of the water. Both iron and hardness are removed from 75%. The two portions are mixed.

Manganese zeolite is a granular material made from greensand zeolite by alternate treatments with manganous sulfate and potassium permanganate. Its capacity for removing iron or manganese is approximately 0.09 pounds per cubic foot and the amount of potassium permanganate required to regenerate it is 0.18 pounds per cubic foot.

In order to remove iron or manganese by this process, all that is necessary is to flow the water through the manganese zeolite filters at a rate of 3 gpm. per sq. foot. As the divalent iron or manganese comes in contact with the manganese zeolite it is oxidized to the insoluble hydrated oxide which is then removed by the filtering action of the granular bed. At intervals, it is necessary to backwash the filter to remove these deposits and the backwash rate used is 8 gpm. per square foot. Regeneration is required in order to restore the oxidizing power of the filter. Depending on the amount of iron or manganese present the flow rate and the number of hours used per day, regeneration may be some 5 to 20 days apart. The regenerant used, as previously mentioned, is potassium permanganate, and the reason why this process is usually limited in industrial or municipal use to waters containing not over 1 ppm. of iron is because potassium permanganate is a relatively expensive material to use as a regenerate. The cost, of course, for removing small amounts of iron is not high, but with larger contents of iron, the cost would be excessive as compared with other methods. A two-unit plant of this type is shown in Fig. 4.

Organic or Colloidal Iron and Manganese

In highly colored surface waters, iron or manganese is frequently present in an organic or colloidal form which cannot be completely removed by any of the foregoing processes. Some highly colored shallow well waters and more rarely a highly colored deep well water will also contain iron or manganese in this form.

In making water analyses, the iron content particularly is often expressed as "Total Iron" and then possibly a portion of this is expressed as "Soluble Iron." If the water contained only ferrous bicarbonate, then the latter figure would be rather meaningless for it would depend on whether the sample had been analyzed immediately, as drawn, or whether it had been partially or completely oxidized and precipitated during the interval between sampling and making the analysis. However, the reason for making this "Soluble Iron" determination on shipped samples is simply so that, if any soluble iron is present, then further tests can be made to see if this soluble iron is merely some which escaped oxidation or if it is due to colloidal or organic iron.

For instance, one clear but highly colored water sample with a color of 450 ppm. had a total iron content of 12 ppm all of which was in solution when the sample arrived in the laboratory some 5 days after the sample had been drawn. Aeration and filtration had absolutely no effect on the iron content even when a detention period of 48 hours was used between aeration and filtration.

Another water, with a color of 35 ppm and an iron content of 3.5 ppm was aerated, the pH was adjusted to 8.3, a detention period of one hour was allowed after which the water was filtered. This treatment only reduced the iron content to 2.6 ppm.

In another experiment in which a highly colored swamp water had 2.0 ppm. each of manganous bicarbonate and ferrous bicarbonate, both expressed as the metals, aeration plus increasing the pH to 10.5 plus one hour detention period plus filtration resulted in removing only a little less than one-half of both the iron and manganese content.

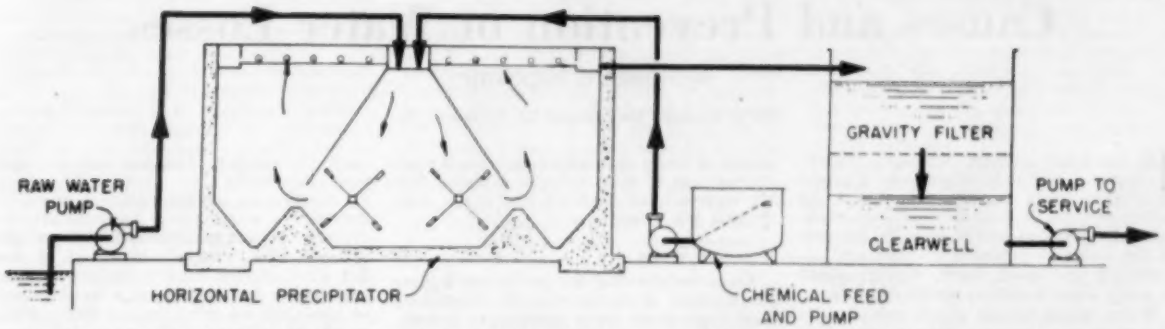

Fig. 5—FLOW DIAGRAM of Spaulding-Permutit Precipitator and filter for removal of organic or colloidal iron and/or manganese by flocculation, clarification and filtration.

Such waters, however, usually respond to coagulation, settling and filtration which removes the iron or manganese as well as the great bulk of the color. It is advisable to run jar tests in the field, on freshly drawn samples, to find what dosage of coagulant is required, what is the most favorable pH range for coagulation and whether or not the use of a coagulant aid, such as clay or activated silica, is also required.

The coagulant usually used is aluminum sulfate as this works well at pH values somewhat below 7.0, say in the range of 5.5 to 6.8. Floc formation should be rapid and the floc should settle quickly. These tests will show what dosages and conditions are required and, under favorable conditions, the content of iron or manganese should be reduced to not more than 0.1 ppm.

The equipment used consists of chemical feeds, reaction chamber and settling equipment or precipitator and floc-former of settling basin type and filters. A flow diagram of this is shown in Fig. 5.

Ferrous Sulfate—Manganous Sulfate

In certain sections, especially in mining districts, acid waters are found —both surface and ground waters. Such waters may contain both ferrous and manganous sulfates as well as free sulfuric acid. Some of these ground waters are so heavily charged with acid and sulfates that they are not worth treating but other ground waters are amenable to treatment. As for the surface waters, the acid content has been so greatly diluted that neutralization usually offers no serious difficulties.

The usual method of treating these acid waters is to neutralize them with either soda ash or lime, aerate or chlorinate if required, settle and filter. There is usually little difficulty in oxidizing and precipitating the iron but the manganese removal may be much more difficult. Raising the pH value or using ripened filters is of value and in a few cases with surface waters where the manganese content is small, permanganate or sodium chlorite (chlorine dioxide) have been advocated to oxidize the manganese.

WEIGHTS OF MATERIALS

Pounds per Cubic Foot — Average

BRICK	
Common Red	100
Silica	105
CEMENT	
Portland	94
Hydraulic	60
COAL AND COKE	
Anthracite	53 to 57
Bituminous	49
Charcoal	18
Coke	26
CONCRETE	
Cement, fine	137
Rubble, coarse	119
EARTH	
Loam, dry, loose	76
Loam, packed	95
Loam, soft, loose mud	108
Loam, dense mud	125
LIME	
Quick, loose lumps	53
Quick, fine	73
LIME STONE	
Large blocks	168
Irregular lumps	96
MASONRY	
Granite or limestone	165
Mortar, rubble	154
Dry	138
Sandstone, dressed	144
METALS	
Aluminum	166
Brass, cast	524
Bronze	534
Copper, cast	537
Copper, rolled or wire	555
Iron, cast	450
Iron, wrought	482
Lead, cast	708
Lead, rolled	711
Steel, cast	490
Steel, rolled	495
Tin, cast	459
Zinc, cast	438
OILS	
Engine	55
Crude	48
Petroleum	55
Gasoline	43
SAND	
Dry and loose	100
Dry and packed	110
Wet and packed	130
Gravel, packed	118
Gravel, bank	111
Gravel, dry	74
WATER	
Water, as ice	59
Water, at 32° F.	62
Water, at 212° F.	60

Causes and Prevention of Water Losses*

by HOMER E. BECKWITH

District Manager, The Pitometer Co., Pittsburgh, Pa.

IN the water industry the term "waste" covers a multitude of sins and it might be well to pause a while to examine the nature of some of these detours from rectitude. No plant, of course, sells 100 per cent of the water it produces. There are unavoidable sources of waste, which produce in every plant a certain irreducible loss.

Water losses may be due to one of more of a number of causes. "House waste" is a commonly encountered problem. Although the losses from individual leaks in this category may be slight, the total amount of water involved can be very great, because of the large number of such leaks. Losses resulting from underground leakage vary from very small quantities to several hundred thousand gallons a day—even exceeding 1 mgd. on rare occasions—for a single leak. The "slow" meter is another source of water loss, which may range from a few gallons a day on a defective house meter to several hundred thousand on a large industrial meter. A fourth cause of water loss is the unauthorized connection, and again the total may vary widely. This problem is not met with very frequently, but, when it does exist, the losses are often staggering. Defective master meters, underread industrial meters and readings spaced so far apart that the meters have turned over between checks are also responsible for registration losses.

Need for Meter Inspection

All accounted-for figures depend upon the accuracy of the master meter. This instrument is usually of the Venturi or orifice type and is kept in an excellent state of repair, registering accurately year after year. But occasionally something happens. It may be the recording apparatus, which can be easily checked and adjusted, but sometimes foreign matter gets into the throat of the Venturi tube or something else happens to disturb the ratio of the areas at the points where pressures are taken. In the older Venturi type, it was usually not easy to inspect this part of the meter, and without inspection no apparatus can be expected to continue to function properly year after year. Pitometer checks had shown a certain meter to be working perfectly as much as thirty years after installation. That is good service. Shortly thereafter further tests indicated that the meter had begun to overregister, a condition which gradually grew worse over the next few years, finally reaching 30 per cent. An inspection revealed that a large stone had worked its way into the tube and upset the pressure ratios, thereby causing the meter to overregister. In a very small number of meters, the pressure ratios have been affected by tuberculation and false registration has resulted, which is hardly surprising after thirty or forty years of faithful service.

Any piece of scientific equipment is entitled to a reasonable amount of care. Modern Venturi tubes are equipped with handholes to make inspection of the internal condition of the tube easy. Experience has shown that all types of master meters—Venturi, orifice plate, pilot tube or current wheel—perform excellently when properly chosen and properly maintained. But occasional independent accuracy checks by means of some instrument such as the pitometer are of great value in insuring that the figures being used for total water production are accurate.

Domestic Waste

Once assured that the production figures are correct, it should next be determined how much of the water delivered to customers is being profitably used or paid for. Originally all water was sold to domestic customers on a "flat-rate" basis. Some effort was occasionally made to control the amount of water used per service by limiting the diameter of the service pipe, sometimes to ½ in. or even less. These attempts proved ineffectual, however, except in holding down the peak demand rate, since they did little to eliminate the small but persistent leaks which continued throughout the day but which were not of sufficient size seriously to affect the pressures or the supply of water for normal use.

There are two methods in general use for controlling domestic water waste. One is the examination of house fixtures by qualified inspectors, either on an overall or a selective basis, with penalties invoked for failure to keep plumbing in a good state of repair. The other method is the installation of meters on domestic services, again either completely or selectively. Which means should be chosen is a matter of economics, depending on the amount of the existing waste and its cost. Some small cities, where there are no sewer systems and where persistent fixture waste will quickly cause cesspools or septic tanks to overflow, may have a per capita consumption of as low as 40 gpd. Unless this water has a high production cost, it may be uneconomical to spend much money to reduce the loss. In other cities, where facilities exist for draining off the waste without inconvenience to the wasteful consumer, the per capita use and waste of water may reach 300 or even 400 gpd. Even with low-cost water, some effort to control wastage is clearly indicated when consumption is anywhere near this high. Inspection and forced repair of defective plumbing fixtures may serve the purpose, but more and more cities are resorting to the metering of domestic services. In order for this method to be effective, the meters must be kept in repair and read at proper intervals.

Registration Losses

The author has always felt that sensitivity is a trait more to be desired in a domestic meter than extreme accuracy. The meter is a mechanical device and it takes energy to move it. The energy necessary for sufficient water to slip around the working parts of the meter and cause a small but steady drip is so little that few if any of the meters in current use will register it. How large an amount can slide through without causing the meter to turn depends on its sensitivity—its inertia or resistance to movement. And the sensitivity of the meter determines the size a fixture leak must attain before it begins to cost the customer money. It must not be forgotten that small drips will usually not register on even the newest and best of the meters in popular use. Such leaks therefore become one of the items in the total of unaccounted-for water. Furthermore, a little reflection will show that the amount lost depends upon the number of meters and not upon how much water flows through the meters. As the average use through each meter increases, the percentage of loss from drip decreases. Meters which may be 100 per cent accurate at a relatively high rate of flow but which do not start to register until an appreciable flow occurs are a fertile source of loss. On the other hand, a meter which causes an increase in the water bill whenever a relatively small fixture leak is permitted to persist makes the customer "waste minded" and cuts down the amount of wasted water.

Loss in registration can also result from too infrequent reading of the meters. The author recalls one city where the careful investigation of a night flow rate of approximately 30,000 gpd. in a single block failed to disclose any indications of underground leakage. Inspection revealed that several meters were turning at a constant rate of ¼ cfm. or more—over 360 cu.ft. a day or 130,000 cu.ft. a year. As the meters were only read once a year, and as the capacity of the reading dial was only 100,000 cu.ft., the meters turned completely over between readings and the customers were billed for only part of the water actually used. There were indications that some of the meters had turned over at least twice between readings. The remedy here manifestly is more frequent readings or an increase in the capacity of the reading dial. Some smaller industrial meters turn over between readings which are six months apart.

Several years ago a survey in a certain small city brought to light the fact that the high loss was almost entirely the result of underreading the large industrial meters. The smallest reading unit on the large meters was ten times the size of the smallest unit on the domestic meters and was so marked. The meter reader, however, paid no attention to the markings and year after year read the meters at 10 per cent of the actual consumption.

In passing, it might be mentioned that cubic-foot meters occasionally get mixed into a system where all the rest are gallon meters, or vice versa, and incorrect readings result.

Another source of lost water, or at least lost registration, is the industrial meter which does not accurately record the flow through it, because the meter is worn out or otherwise defective, or because it is improperly set or unwisely selected. Manufacturers make several types of meters, each of which is especially designed to do a certain kind of work. Some perform best under high continuous flows, some under relatively low flows and some under a combination of both. Moreover, the manufacturer's instructions about setting the meter must be followed or incorrect registration may result. Satisfactory service can be assured only if meters are correctly chosen as to type and size and are properly set.

Meters are mechanical instruments and even the best machines eventually wear out. Although registration may continue, worn gears and other frailties of old age gradually decrease meter accuracy. Meters are the cash registers of the water works system and justify every bit of attention and care required to keep them in proper working condition.

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Occasionally it would be found that industrial customers are taking water through unauthorized connections or unmetered fire lines—often in spectacular amounts. The author knows of one plant which took nearly 2 mgd. and had apparently been doing so for 25 years. It is remarkable, however, that in most such instances the top management of the offending company has no knowledge of what is taking place. Some minor official is usually just trying to make a showing. Most people are honest.

Underground Leakage

The source of greatest losses is the hidden, underground leak, which may vary in size from a few gallons a day to over a million. Underground leaks occurring on mains are usually due to blown joints, broken or split mains, holes, rotted wooden plugs and the like. Those on services are due principally to broken corporation cocks, defective wiped joints, blown gaskets, split pipe, or pipe disintegrated by corrosion or electrolysis. The escaping water gets into sewers, gravel beds, culverts, streams, limestone caves and so forth. Even after more than 25 years' experience in detecting and locating leaks, the author is frequently surprised by some new combination of circumstances which will permit water to escape from such a leak without any surface indication of its existence. The increase in the amount of paved streets has been a factor in keeping many leaks hidden.

As previously stated, some leaks are too small to be detected by any presently known method, and, even if they were definitely located, the cost of repairs would be excessive. These small leaks are an important factor in irreducible losses. Here again, the amount of loss depends on the size and number of the mains and not on the quantity of water they carry. If the water use from a particular pipe were doubled, the increase would not cause a single gallon more to be lost from that pipe. In other words, the percentage ratio of the seepage to the use would be cut in half.

Other factors, such as leakage and evaporation from reservoirs, also contribute to the irreducible loss.

Water Waste Surveys

The three principal causes of irreducible losses are fixture drips too small to register on meters, small seeps from mains, and evaporation and other reservoir losses. None of these three bears any direct relation to the amount of water put into the system. For this reason, it is impossible to give any overall figure for reasonable losses. Some plants should, and do, account for approximately 90 per cent of the water produced. Others, with a very low per capita use or an excessive main mileage in relation to the amount of consumption, can under the best of conditions account for only a much smaller percentage. It requires a water waste survey, planned in such a way that it will detect and locate all of the preventable sources of waste, to determine what the unavoidable loss is on any particular system.

The pitometer water waste survey is intended to be that type of survey. It is based upon a series of direct and indirect measurements with the pitometer which determine the amount of water entering the system and its distribution throughout the system. A properly designed pitometer survey has several functions:

1. It checks the master meters for accuracy by independent comparative flow measurement.

2. It divides the distribution system into districts containing a few miles of main each and obtains a 24-hour measurement of the total flow into each district, together with the variation in that flow.

3. It tests large industrial meters for accuracy by independent comparative flow measurement.

4. It checks large industrial plants for unauthorized connections, again by flow measurement.

5. It determines the distribution of the night rate of flow almost block by block, so that the location, as well as the amount of the waste, can be determined. Through further investigations conducted by suitable methods wherever these measurements show abnormal flows, all leaks are definitely located for repair and all other sources of waste are disclosed.

That is to say, the survey tells where the water goes and why it goes there. It eliminates guesswork and clearly shows the exact nature of the waste, so that remedial steps may be taken. Underground leaks are located and can be dug up and repaired. If residential waste is involved, the responsible areas, or even individual properties, are discovered, making possible the elimination of the waste by inspection and repairs or by metering. Defective industrial meters or unauthorized industrial use is detected, and the meters can be repaired or replaced. If it is found that meters are not being read often enough, the period between readings can be shortened. Once the disease has been correctly diagnosed, the remedy is clearly indicated.

When such a survey has been made and all the waste stopped, then and only then can the percentage of "unavoidable" waste for a particular plant be determined.

A question frequently asked is what size of community can profitably make a water waste survey. The answer is that there seems to be no maximum or minimum limit. Some of the most outstandingly successful surveys have been made in communities of more than a million population, while others have been equally successful in communities of less than a thousand population. A single leak wasting 50,000 gpd. would be a very small item in a system using 100 mgd., but in a small community with a total daily consumption of 100,000 gal. it would amount to half of the output. Although most of the really large individual leaks have been found on the larger systems, the surveys which have resulted in the highest percentage of water loss reduction have usually been made on smaller plants. The operation of the survey is flexible, and methods are readily adaptable to the various field conditions encountered—including the size of the community.

The amount of "preventable" waste which should be permitted to exist before a determined effort is made to locate and eliminate it depends on the value of the water—its cost of production, the quantity available and other widely varying factors. The least valuable water is probably that taken from a gravity supply having surplus storage and transmission capacity, although as the demand approaches the capacity of the plant this water can become extremely precious. Most expensive is the water obtained from limited supplies with high purification and softening costs. Each system has to be studied upon the basis of local conditions, but there will always be a point at which waste becomes too costly to be tolerated. When that point has been reached or passed, a careful, scientifically planned survey such as the one previously outlined will best serve to bring the losses down to a minimum.

BLOTTING OUT WASTE

Safe Water
delivered night and day
Costs Less
than anything else you buy
· · but · ·
Don't Ignore Leaks!

* * *

Satisfied customers are worth more to us than revenue secured from water uselessly passing through meters.

INDIANAPOLIS WATER CO.

What Leaks May Cost

Size of Leak		Gallons per 24 Hours	Gallons per Month	Cost per Month
½"	◯	47,600	1,451,800	$156.21
¼"	○	12,300	375,150	60.05
⅛"	o	3,200	97,600	19.65
1/16"	o	860	26,230	6.35
1/32"	•	215	6,550	1.97

[Above estimates are based on Indianapolis pressure without allowance for friction loss]

The above is a reproduction of the top side of a little blotter sent out to customers, reminding them of the high cost of allowing fixture leaks to persist. If as good at blotting waste as ink, the scheme is praiseworthy.

Incidentally, the Indianapolis Water Company gets in a good public-relations message about satisfied customers being worth more to them than the added revenue from the uselessly metered wastage.

Water Use by Air-Conditioning Equipment*

by LEWIS L. BARNES

Chief Engineer, Carrier Atlanta Corp., Atlanta, Ga.

BECAUSE of the growth of the air-conditioning industry, water use by air-conditioning equipment has become increasingly significant. Some municipalities have been forced to invoke restrictive measures; others may soon find they must take similar steps; but still others may never find it necessary to follow this course. It is therefore appropriate to take a clear view of the subject at this time in order to evaluate its importance and study corrective measures if applicable.

The term "subject" is used rather than "problem" because the consumption of water by air-conditioning equipment is not necessarily a problem unless local factors make it one. A study of this water usage should be entirely local in scope, and since so many local conditions complicate or simplify the problem, this discussion will, of necessity, be held to generalities, with no attempt being made to recommend procedure for purely local situations.

Condensers

All air-conditioning systems employing mechanical refrigeration require some means of cooling the compressed refrigerant gas in order to condense it back to the liquid

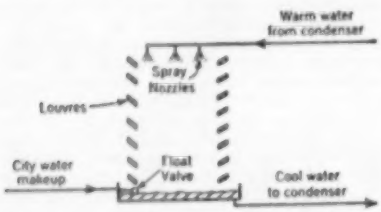


Fig. 1. ATMOSPHERIC cooling tower

state. One of the most popular methods is the use of the air-cooled condenser, but unfortunately its overall efficiency is so low that it is not generally practical except in very small installations.

On larger installations, it is quite common to use a water-cooled condenser, employing the public water supply as the cooling medium. This device usually consists of a shell-and-coil type of heat exchanger, with water passing through the coil and cooling the refrigerant gas which comes in contact with the outside of the coil. In this process, the temperature of the water is raised to a point at which it is no longer useful as a cooling agent and must be rejected in favor of water at a lower temperature. There is obviously a continuous flow of water through the condenser while the equipment is in operation, amounting to approximately 1.5-2.5 gpm. per compressor horsepower at full load. It is apparent that this method can result in the wasting of large quantities of water which has undergone no other change than that of a 15-20°F. rise in temperature. For example, a 10-hp. air-conditioning compressor, using city water at the rate of 2.0 gpm. per horsepower, consumes 20 gpm., 1,200 gph. and 9,600 gal. or 1,270 cu.ft. per eight-hour day. These figures may not be impressive to those accustomed to thinking in terms of millions of gallons per day, but with a multiplicity of installations, the water consumed can become a significant load on

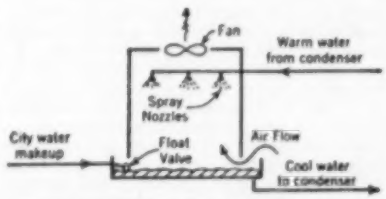


Fig. 2. INDUCED-DRAFT cooling tower

the city water mains. Whether this load is desirable or undesirable depends on local conditions, but it must be borne in mind that it generally occurs during the summer months and may coincide with other peaks.

The air-conditioning installation just described is relatively low in initial cost to the owner, but, depending on local water rates, could be quite expensive to operate because of the high water consumption. Installations of this type are usually equipped with an automatic water-regulating valve to insure against using more water than is required under less than the maximum load. It has been the author's experience that these valves are adequate for adjusting water flow to meet load conditions but should not be relied on to effect complete closure during shut-down periods. It must not be overlooked that, in certain localities, the disposal of waste condenser water constitutes just as great a problem as does the supply of this water in other localities.

The wasting of condenser water could sometimes be objectionable on account of inadequate supply or disposal facilities, high costs, high initial temperatures, poor chemical characteristics and other factors. It is well to consider, therefore, some of the most common means of combating this problem.

Conservation Devices

The water-cooled condenser described previously can be used in conjunction with a cooling tower or spray pond, which, if properly designed and installed, can recapture approximately 95 per cent of the water otherwise wasted. This saving is accomplished by re-cooling the warm water discharged from the condenser and returning it to the condenser by means of a circulating pump.

The atmospheric cooling tower (Fig. 1) depends entirely on natural wind and air currents to cool the condenser water effectively. It is suitable for location only in places where free and unobstructed air flow is available. Many installations of this type have failed to produce the desired results because the tower was located in a light court or on the lee side of some obstruction.

The induced-draft cooling tower (Fig. 2) is equipped with a motor-driven fan to create its own draft. This type can be located in many positions which would be unsuitable for the atmospheric tower, but obviously its initial cost is greater.

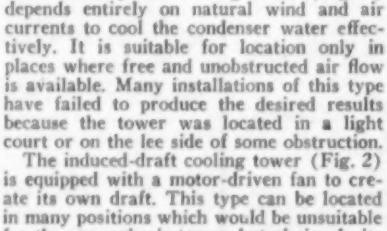


Fig. 3. SPRAY pond

The spray pond (Fig. 3), commonly used as a water conservation device, has certain advantages as well as disadvantages when compared with cooling towers. Job conditions should govern the choice.

The cooling towers and spray pond will perform the desired task of water cooling with varying degrees of efficiency, depending on local conditions. They are all readily suitable to existing water-cooled installations, with the adaptation usually consisting of simple piping changes and the addition of a circulating pump. It should be remembered that the addition of the water-circulating pump will increase the use of power, a fact which must be considered when evaluating operating costs.

The evaporative condenser (Fig. 4) is one of the most efficient means of condensing with minimum water requirements. In this device, the refrigerant gas is cooled directly by a combination of air and spray water passing over the condensing coil. Only one heat transfer is necessary (gas to water and air), as contrasted with the cooling tower or spray pond, which require two heat transfers (gas to water, and water to air). The evaporative condenser is very compact and frequently can be placed in locations which

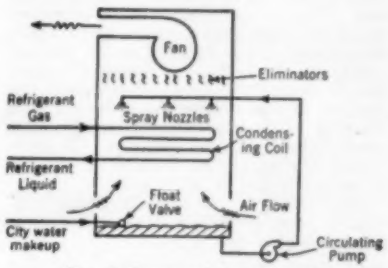


Fig. 4. Evaporative condenser

are not practical for cooling-tower installations. On new installations, the evaporative condenser compares favorably in first cost with cooling towers and spray ponds. If water-conserving equipment is to be applied to existing water-cooled equipment, the cooling tower is usually cheaper than the evaporative condenser, in that the tower installation continues to utilize the existing water-cooled condenser.

From the viewpoint of those in the business of supplying water, the subject can be summarized by stating that:

1. The water load imposed by air-conditioning equipment can be attractive to those systems which have ample water for sale during the summer months.

2. This load can be unattractive to those systems which have a deficiency of water in the summer if the return from water sales will not justify additional investment in plant or distribution facilities.

Water systems which cannot stand this load imposition must work out the problem through local channels. Some cities have been forced to invoke restrictive ordinances to prohibit the indiscriminate wasting of water. All ordinances of this nature should be flexible enough to prevent undue hardship. Some thought should be given to the possibility of instituting demand charges to compensate for the standby facilities when no water is being used.

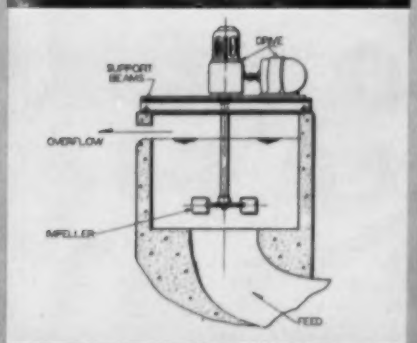
*Reprinted from JAWWA, Vol. 41, p. 437 by permission.

BULLETIN # 6042

Dorr-Oliver

Equipment and Methods for Modern Water Purification and Sewage and Industrial Waste Treatment

An outline of the major equipment units of the complete Dorr—Oliver line for municipal and industrial sanitation arranged in flowsheet order.



EQUIPMENT	DISTINGUISHING CHARACTERISTICS	APPLICATION
WATER PURIFICATION		
PRE-SEDIMENTATION		
Dorr Pre-sedimentation Thickener Up to 50 MGD and 10,000 tons solids per day per unit.	Raking mechanism for circular tank, designed to collect and concentrate settled material to a central discharge cone.	Particularly adaptable where turbidity exceeds 1,000 ppm. Use results in chemical savings and reduced load on secondary basins.
MIXING		
Dorrco Flash Mixers From 0.5 to 40 MGD per unit. Bulletin No. 6971	High-speed, motor-driven mixing unit equipped with turbine-type impeller for intense mixing in few seconds.	Whenever complete diffusion of chemicals through raw water is desired instantaneously to avoid floc formation in mixing chamber proper.
FLOCCULATION		
Dorrco Flocculator* From 0.1 MGD up. Bulletin No. 6971	Motor-driven revolving paddle wheel elements set in rectangular basin. Gentle mixing causes build-up of uniform flocs of excellent characteristics.	Whenever finely-divided or semi-colloidal solids are present in raw water, the use of Dorrco Flocculators will increase plant capacity and reduce chemical consumption.
CLARIFICATION		
Dorr Clarifiers and Monorakes* From 0.1 MGD to 30 MGD per unit. Bulletin Nos. 6191 and 6091	Both center-shaft and center-pier Dorr Clarifiers equipped with rotating raking arms for round or square tanks. Dorrco Monorake is a balanced raking mechanism for use in rectangular tanks.	Continuous removal of settled solids from clarified raw water, sewage or industrial waste.

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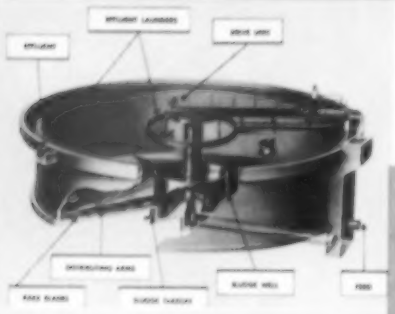
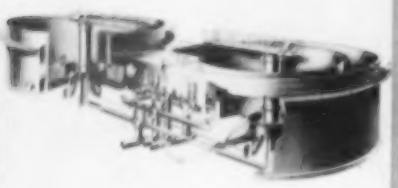
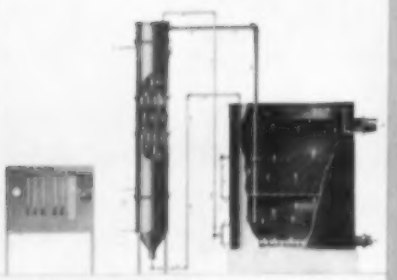
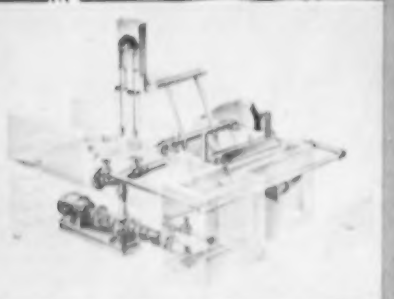


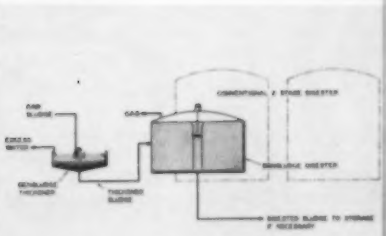


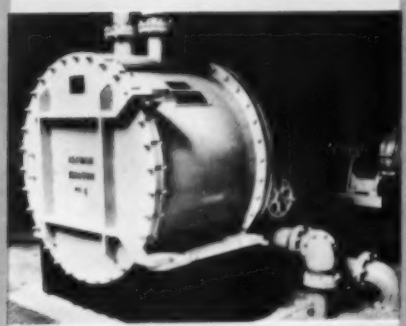


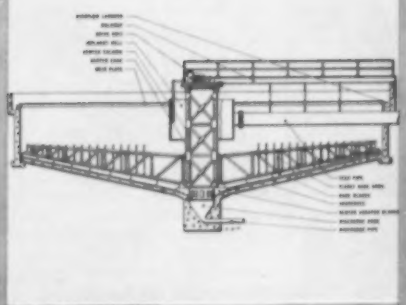


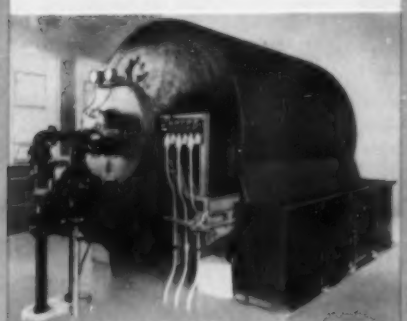
EQUIPMENT	DISTINGUISHING CHARACTERISTICS	APPLICATION
COMBINATION UNITS		
Dorrco Hydro-Treater® From 0.2 to 30 MGD per unit. Bulletin No. 9041	Complete, self-contained high-rate unit providing for flocculation, thickening, clarification and positive sludge removal in a single tank.	For softening, color or low turbidity removal.
Dorrco Clariflocculator®	See sewage and industrial waste treatment.	
Dorrco Aldrich PeriFilter System From 0.1 to 5.0 MGD per unit. Bulletin No. 9042	Normally consists of two or more Dorr pre-treatment mechanisms each surrounded by an annular rapid sand filter.	For chemical pre-treatment followed by sand filtration to remove turbidity, color and hardness.
ION-EXCHANGE		
Dorrco Hydro-Softener From 75 to 800 GPM. Bulletin No. 4083	Uses base or cation exchange resins for continuous softening. Resin is continuously regenerated with brine.	For softening comparatively clear water to make it satisfactory for usual domestic needs.
SEWAGE AND INDUSTRIAL WASTE TREATMENT		
SCREENING AND GRINDING		
Dorrco Bar Screen Up to 75 MGD per unit. Bulletin No. 6400	Mechanically operated automatically activated unit consisting essentially of bar racks cleaned by motor-driven rake.	Every sewage and industrial waste treatment plant where removal of sticks, rags and other large solids is required.
Dorrco Sulzer Disintegrator 60 cu. ft. of screenings per hour. Bulletin No. 6400	Motor-driven, heavy duty screenings macerator. Consists of low-head pump with fixed and rotating cutting blades arranged in front of a perforated screenings plate.	For the maceration of sewage screenings. Especially adaptable in combination with Dorrco Bar Screen.
GRIT REMOVAL		
Dorr Detritor® From 0.25 to 140 MGD per unit. Bulletin No. 6411	Continuous, mechanically operated grit chamber consisting of separate grit collecting and grit removal and washing mechanism.	For the removal of grit of 65 mesh or coarser from raw sewage or industrial waste.
CLARIFICATION		
	See water purification.	

EQUIPMENT	DISTINGUISHING CHARACTERISTICS	APPLICATION
TRICKLING FILTRATION		
Dorrco Distributor From 0.1 to 27 MGD per unit. Bulletin No. 6300	Two or four-arm rotary, self-propelled unit for even distribution of liquid wastes over filter bed.	Equally applicable to low or high-rate trickling filter treatment for oxidizing organic matter in solutions.
SLUDGE DIGESTION		
Dorrco Densludge Digestion System Combines Grit Washer, Densludge Thickener, Digester and Heat Exchanger to meet any sludge digestion problem. Bulletin No. 6262	Incorporates Densludge Process (described below) with integrated digestion control system which reduces capacity requirements up to 80% over conventional methods.	For digestion of organic solids from any primary or secondary treatment flowsheet at maximum volume utilization.
SLUDGE HEATING		
Spiral Heat Exchanger 110,000 to 1,530,000 BTU per hour rated capacity per unit. Bulletin No. 6281	External element for heating of sewage sludge. Consists of two concentric spirals welded together to form alternate hot water and sludge liquor passageways.	Provides simple, high-efficiency and easily controlled means of externally heating contents of any digester.
SLUDGE THICKENING		
Dorrco Densludge Process For plants treating from 0.5 MGD up. Bulletin No. 6260	Clarification and thickening are carried out separately. Dorr Densludge Thickener produces a sludge with up to 50% less volume.	For both activated sludge and trickling filter plants to increase digester capacity and other sludge handling facilities.
FILTRATION		
Oliver Sewage Sludge Dewaterer From 65 sq. ft. of filtering area in "package" units to 570 sq. ft. in standard individual units.	Low submergence drum type continuous vacuum filter available in a variety of corrosion resistant material to meet any sludge dewatering problem.	Removes 80% to 85% of the water from raw or digested sludges produced in any primary or secondary treatment plant.
COMBINATION UNITS		
Dorrco Vacuator* From 0.5 to 30 MGD per unit. Bulletin No. 6301	Cylindrical tank with dome roof employing principle of vacuum flotation. Makes three product separation of floatable material, improved effluent and a sludge containing appreciable quantities of grit.	For scum and grit removal ahead of primary sedimentation; for complete primary treatment; for sole treatment in coastal areas.









EQUIPMENT	DISTINGUISHING CHARACTERISTICS	APPLICATION
COMBINATION UNITS Cont'd.		
Dorrco Clariflocculator From 0.1 to 10 MGD per unit.	Provides mechanical flocculation in inner compartment, clarification and positive sludge removal in outer annular compartment.	For clarifying raw or chemically treated municipal and industrial wastes.
Dorrco Aerator-Clarifier From 0.1 to 7.5 MGD per unit.	Contains cylindrical aeration chamber of steel with partially closed bottom, concentric with Clarifier. Standard sludge raking mechanism. Air introduced by fixed diffuser tubes.	For the preaeration of raw sewage. Grit or heavy solids will not interfere with operation of unit.
Currie Claruator Up to 25 MGD per unit. Bulletin No. 6581-C	Combination aerator and clarifier with clarification taking place in round or square central compartment and aeration in outer annular compartment.	For the clarification and aeration of sewage or industrial wastes in the activated sludge process.
Dorr Clarigester® From 0.1 to 1.25 MGD. Bulletin No. 6691-C	Mechanically equipped two-story tank combining clarification in top compartment and controlled, separate sludge digestion in lower compartment.	Ideal for small sewage or industrial waste plants either as sole treatment unit or in combination with other treatment steps.
Dorr Duo-Clarifier Duo-Filter and Duo-Clarigester From 0.1 to 1.25 MGD per unit. Bulletin No. 7312	The "Duo" units are designed for two-stage treatment in a single structure. The Duo-Clarifier provides primary and secondary clarification in one tank; the Duo-Filter consists of two stages of filters arranged concentrically; the Duo-Clarigester provides two stages of clarification plus separate sludge digestion in a single structure.	Particularly adaptable for treatment of domestic sewage from small communities and isolated establishments with contributing populations of over 500 and industrial wastes requiring biological treatment.

for more detailed information, write, wire or phone the nearest of the following offices . . .

Stamford, Conn.	Barry Place	St. Paul 4, Minn.	2631 University Avenue
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OFFICES, ASSOCIATED COMPANIES OR REPRESENTATIVES IN THE PRINCIPAL CITIES OF THE WORLD

®TRADEMARK REG. U. S. PAT. OFF.

VI—SEWAGE WORKS OPERATIONS

SEWAGE is the used water supply of a community. It must be disposed of in some manner. Disposal to the nearest water course or other body of water is the common practice. If that body of water cannot assimilate the sewage without a nuisance being created, then the sewage must be treated.

Characteristics of Sewage

Sewage is composed of approximately 99.9 per cent water and approximately 0.1 per cent solids. These solids exist in three forms; dissolved, colloidal and suspended. The proportions of these forms of solids varies depending on the source of the sewage, and extent to which sewage matter has been broken up and dispersed during its flow through the sewers.

These sewage solids are a combination of organic and inorganic substances. It is the organic matter which is subject to decomposition under the influence of bacteria and it is this decomposition which causes a nuisance. Sewage treatment consists of several processes which control the decomposition of organic matter in sewage and prevent nuisance.

Since sewage consists of wastes from human habitations as well as from industry, it is expected that the organic matter will include fats, carbohydrates and proteins.

Those solids which can be filtered out on an asbestos mat or filter paper are termed suspended solids. Some of these solids, which are heavier than water, will settle under quiescent (or almost quiescent) conditions; these are known as settleable solids. Extremely finely divided solids which will not settle and cannot be filtered out are termed colloids or dispersed solids. Matter which is in true solution is termed dissolved solids.

Organic matter in sewage can be burned off and when determined in that manner is termed, volatile matter. The fixed residue after burning is termed, ash. In addition to the solids present, sewage contains billions of bacteria, which make up part of the colloidal and non settleable solids. These bacteria may be attached to solids or free floating and are continually at work decomposing the organic matter present.

From the standpoint of material classification, sewage contains grit, garbage, paper, rags, feces, matches, and various other substances which are used in the home. In the average community having some industry, sewage also contains industrial wastes, many of which contain large amounts of organic and inorganic substances.

Stream Pollution

Inasmuch as sewage contains organic matter, undergoing biological decomposition, and since most of this matter is in a reduced state, there exists a demand for oxygen to oxidize and stabilize the substance. It is this demand for oxygen which leads to nuisance conditions.

For many years sewage was dumped into the nearest water course or other body of water. Since natural waters contain a small amount of oxygen, decomposition of sewage could go on with oxidation of the organic matter present. Thus the stream was said to have a capacity for "self purification." When organic matter, in excess of that "capacity" is added to the stream a nuisance results; the stream becomes foul.

Solids settle out in sludge banks and decompose producing gases and odors. When the oxygen of the stream is used up, anaerobic bacteria fluorish and reduced organic compounds and sulfides are produced. The stream becomes black in color and foul in odor. Fish die from lack of oxygen. Gradually, as the organic matter is decomposed while the stream moves on, oxygen is taken up (reaeration) and the stream returns eventually to its original condition. From this situation arose the much overworked "self purification" of streams.

Collection

Water is transported to consumers under pressure but sewage is collected in a network of sewers and transported usually by gravity to some central point for disposal or treatment.

The sewer system is composed of laterals which discharge into a branch sewer which in turn discharges into a main sewer, sometimes called a trunk sewer. An intercepting sewer receives the dry weather flow of a number of trunk sewers and carries it to a treatment works or outfall into a body of water. When both sanitary sewage and storm water enters a sewer system it is known as a combined system. In modern practice separate storm water sewers are used to keep the street wash and runoff out of the sewage treatment plant.

When sewers must be located at elevations which will not allow gravity flow to the treatment plant or outfall, then the sewage must be pumped. This is done at lift stations which take sewage from the low elevation and discharge it to a higher level from which it can flow by gravity to its ultimate disposal.

Treatment

Sewage is treated to eliminate or reduce its nuisance characteristics. Treatment may consist of the removal of suspended matter, the oxidation of organic colloids, and the killing of harmless bacteria. The choice of processes used for treatment depends primarily on the extent of treatment necessary.

Primary treatment is the term applied to operations by which suspended solids are removed. These operations include the removal of grit, screenings, and settleable organic solids. Sometimes as an aid to primary treatment, chemical precipitation, flocculation aeration and vacuum flotation are used.

Secondary treatment involves the functioning of aerobic bacteria which precipitate and oxidize colloidal and dissolved organic matter. Oxygen of the air is essential to this process which may be carried on in two ways. Sewage may be allowed to trickle over exposed surfaces of rock on which the organisms grow or air may be blown through the sewage in which flocs of biological organisms develop and grow. The first process is carried on in a trickling filter, the second is termed the activated sludge process. Aids to these two processes include preaeration, roughing filters and chlorination. The activated sludge process has several variations.

Another secondary treatment process is termed contact aeration. In this process, sewage is passed over or by surfaces on which organisms grow.

while air is being blown through the flowing sewage. A variation of this process is the old contact bed in which tanks filled with stones are alternately filled with sewage and emptied to allow air to come in contact with the biological growths on the stones.

Disinfection

All sewage contains pathogenic or harmful organisms. In the course of sewage treatment by secondary treatment processes, most of these harmful bacteria are removed or destroyed. Sewage treated solely by primary processes still contains large numbers of bacteria, including harmful types. In order to reduce the number of bacteria remaining in sewage after treatment, chlorine is used for disinfection.

The addition of chlorine must be controlled to produce the extent of bacterial kill desired. Much of the chlorine added is simply used up in chlorination of organic and inorganic substances in the sewage; a small percentage of the chlorine is used in actually killing the bacteria. Generally speaking no attempt is made to sterilize the sewage (that is to obtain a 100 per cent kill) but disinfection should be carried on to reduce the bacterial content to a level which suits the receiving body of water.

Hypochlorites have been used in small plants but the use of chlorine gas fed by special devices is more common. The point of addition, time of contact and other conditions are important factors in disinfection.

Solids Disposal

Probably the biggest problem in sewage treatment is what to do with the substances which are removed from the liquid. These substances, most of which are high in nuisance characteristics, include sand, cinders, rags, garbage, leaves, matches, paper, greases, and organic sewage solids in various states of subdivision and a variety of miscellaneous objects not normally thought of as being a part of sewage. The handling and treatment of solids presents some of the most difficult, involved, and annoying problems of sewage treatment.

Large objects such as rags, corks, leaves, rubber balls, overshoes, etc. are removed by a screening process. These screenings may be buried, burned or ground and returned to the sewage for later removal.

Heavy inert matter such as sand, gravel, cinders, (generally termed grit) bottle caps, etc. will settle out if the velocity of flow is reduced. This grit can then be removed and disposed of as fill. Unfortunately some organic matter may also settle out with the grit.

Greases usually are removed as skimmings in sedimentation tanks where the organic matter settles out. The former may be burned or added to the solids, which settle out, as they are discharged to a process for further treatment and disposal.

Solids which are removed in primary treatment are termed raw sludge, solids from trickling filters are termed humus, and solids from the activated sludge process is called activated sludge.

Digestion, Dewatering and Drying

Sludge of any kind, including greases, can be decomposed in tanks in the absence of air. It cannot be disposed of on the ground because it will decompose and cause a nuisance. It can be decomposed in lagoons or barged to sea for disposal.

The most common treatment is digestion in closed, heated tanks where the sludge is kept for a period of a week to a month, during which time carbon dioxide and methane are given off and the sludge decreases in volume and mass. When digestion is complete the sludge can be removed for disposal by dewatering and drying on sand beds or by chemical coagulation and dewatering on vacuum filters followed by drying or incineration in a furnace.

Maintenance

One of the big problems in operation of sewage works is maintenance, including maintenance of both the sewer system and the treatment.

Solids both organic and inorganic tend to settle or strand in sewers, particularly if constructed on a flat grade. This is especially true of grit particles which enter house sewers through washing of vegetables, etc. In combined sewer systems, grit, sand and cinders from street flushing add to the problem of stoppage of sewers; tree roots also cause sewer stoppage.

Ordinances to keep grease and other undesirable wastes out of sewers, is one method of reducing sewer cleaning problems. Methods of removing stoppages include regular flushing, cleaning with rods, drag lines, buckets, and other devices. Root growth is minimized by adding copper sulfate at the upper end of a sewer.

Maintenance of treatment works facilities includes proper lubrication on schedule of all mechanical equipment, painting of building, protection against excessive humidity, removal of grease from tanks, etc., a scheduled inspection, repair and replacement program for all moving equipment. General cleanliness of all operating areas is an essential part of maintenance.

Laboratory Control

In the operation of sewage treatment plants, laboratory control is an essential function. The size of the laboratory and the number of tests performed depend on the capacity of the plant and the extent of treatment operations. Since the purpose of treatment is to remove nuisance causing substances, tests, which measure these substances and determine the extent of removal, should be included in the laboratory operations.

Tests for solids removal include the simple volumetric Imhoff cone test, suspended solids by Gooch filtration, settleable solids by weight, and total solids by evaporation (especially on sludge). Oxygen demand is determined by the 5-day B.O.D. test; chlorine requirements by the chlorine demand test. Other tests, which may be made, include nitrogen in its various forms, alkalinity, bacteria, especially the most probable number of coliform organisms. Sludge digestion, dewatering and incineration require tests of volatile matter in sludge, gas analysis, volatile acid determinations, coagulant dosage requirement, and moisture content: The more complete the laboratory program, the better plant control possible.

Miscellaneous Problems

There are other problems in sewage works besides maintenance, operation and repairs. Management must be alert to maintaining good public relations. This involves keeping the sewage plant attractive and free from odors, keeping flooded basements at a minimum, keeping salaries of employees at the highest possible level, publicizing the good work of the treatment plant through newspapers, magazine articles and talks to local service clubs.

In some cities the problem of industrial wastes loom large. Not only do industrial wastes present problems of operation but they present problems of charges for handling. Financing of treatment works and sewers likewise presents problems to management. Both of these subjects are discussed elsewhere in this issue of The Reference and Data Edition.

The Equitable Use of Streams*

by SETH G. HESS

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AS AN INTRODUCTION to this paper it is desirable to establish its ultimate purpose. A rational method is developed for allocating the absorptive power or capacity of a stream to assimilate pollution. Engineering judgment to determine the degree of treatment required cannot, however, be relegated to a secondary position. This thesis is offered, not as the ultimate method, but rather as the basis of discussion.

Philosophy of Stream Control

Those working in the field of pollution control are approaching unanimity in a recognition that streams and waterways are used for many purposes. It is quite generally accepted that all streams cannot be maintained in their state of pristine purity, and it is likewise generally accepted that it is improper to permit the degradation of a stream to a point below quality standards consistent with the expected use of the stream that can be attained within reasonable economic limits.

Uses of Streams

The purposes for which streams may be used have been well developed. Among the uses of a body of water may be included the following:

1. Potable water supply and domestic uses.
2. A source of protein food: namely, fish and shellfish.
3. Shipping.
4. Aquatic recreation.
5. Wildlife.
6. Water for agriculture and animals.
7. Raw material for industry.
8. Power.
9. Other industrial uses, such as cooling and condenser water.
10. Fire protection, street flushing, and other municipal uses.
11. Receipt of drainage water from swamps or other flooded lands.
12. Carriage of wastes.

It is recognized, therefore, that streams are used for many purposes and presently it is quite generally accepted that one of the proper uses for a stream or waterway is to carry away wastes. The uses at first glance appear incompatible; however, it is known from experience that a stream may indeed be used for many purposes providing there is judicial control and a recognition of the fundamentals of the Golden Rule. What, therefore, is the principle upon which one allocates rights and establishes obligations so that the most effective use of the stream may be obtained?

Stream Classification

Clear differentiation should be made between stream classification and stream standards. By classification is meant an enunciation of the use that is expected to be made of the stream or a portion of the stream. Emphasis, for a moment, should be placed on the word "expected." If streams are classified on the basis of their present use, it could hardily be expected to improve stream conditions. Obviously, a great deal of judgment must be exercised in determining the expected use. It is customary, however, to hold public hearings before a stream is classified, thereby giving ample opportunity for all to be heard and to express their opinions concerning the reasonable use that is expected to be made of the stream following any reasonable exercise of control of pollution. Perhaps it might be preferable to use the term "desired" rather than "expected" use.

Stream standards, on the other hand, refer to the quality standards which the waters of the stream must attain in order to sustain the purpose for which the stream is classified. Standards are, in general, physical, chemical, bacteriological, biochemical, or other means of measuring the stream quality.

There are additional criteria for water pollution control which deal with the quality of the wastes to be discharged from a given plant, usually termed effluent standards. The effluent standards are exemplified by the standards of the State of Pennsylvania, of the Interstate Commission on the Delaware River Basin, of the Interstate Sanitation Commission, and others.

Effluent standards, which have some advocates, have the advantage of simplicity and definitiveness. In some areas they are well adapted; however, water quality standards are being generally adopted at the present time.

Stream Standards

Some of the established water standards are based on an effect or a potential effect, such as the Florida State Sanitary Code, which declares a menace to health is created "when acids, alkalis, or other chemicals or deleterious substances are discharged into waters so as to interfere with the biochemical functioning of the stream or waters, or where such wastes kill or interfere with the normal development of fish or other foods derived from waters." The Indiana Stream Pollution Control Board Regulation states: "Floating material including grease and oil shall not be discharged into any surface water in deleterious amounts or in amounts sufficient to affect injuriously fish life, fur-bearing or domestic animals, or the general biology of the water, or plant life in or in the vicinity of such water." On the other hand, the tentative water classification standards of the State of Maine provide definite numerical limits for dissolved oxygen, biochemical oxygen demand, pH, and *B. coli*. The Maryland Water Pollution Control Commission, in addition to the aforementioned criteria, has added numerical limits for fluorides, chlorides, phenolic compounds, iron and manganese, color and turbidity. The New York State Water Pollution Control Board, in addition to some of the above, has numerical limits for ammonia and ammoninum compounds, cyanide, ferro- or ferricyanide, copper, zinc, and cadmium. These are but a few examples.

What Next?

Here a break is made with tradition and the reader is asked to receive the remainder of these remarks with an open mind. To recapitulate: Present practice determines the use to which a stream is expected to be put, and as a result of that, indicates a

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definite clasisfication for a part or for all of that stream. Following that, sufficient treatment must be given so that the established water quality standards for that particular classification shall not be violated. Here the question should be asked as to what degree of treatment is required to assure that the water quality standards are not violated. The usual approach is to require that the polluter determine the treatment facilities necessary to meet the established standards. It is usual that plans for such facilities must be submitted to a regulatory agency for approval. That agency, however, must take into consideration that this polluter is not the only one having rights to the capacity of that stream to assimilate pollution. A regulatory agency is usually reluctant to assign to any one polluter or any group of polluters the total capacity of the stream to assimilate the pollution load that remains in the effluent.

Regulatory authorities have not yet adopted a formula for determining how much of the assets of a stream shall be allocated to a single contributor. It does not appear equitable to permit a single municipality or a single industry to usurp the entire capacity of a stream to assimilate pollution, even though in doing so the stream is not despoiled to a point below the established standard for that stream. Certainly a future contributor—in the sense of time, not location—has certain rights to use that stream. A downstream occupant has rights to the waters of a stream, even though he may not exercise those rights for years to come.

Common law conceives that riparian rights provide for the reasonable use of a stream by the downstream owner. A definition of "reasonable" has long plagued jurists and it has been bracketed between the concept of "without material change in either quantity or quality" to the other extreme, which holds that wastes from some regional industry, such as the mine wastes in Pennsylvania or industrial wastes for which no reasonable methods of treatment have been evolved, may be discharged into the stream regardless of the damage to the stream and the downstream owners.

Total Assimilating Capacity

The allocation of the entire assimilating capacity of a stream has been advocated. Under such a proposal the assimilating capacity of the stream is reallocated as each new contributor is about to add to the pollution load. Regulatory authorities have been reluctant to accept this thesis with its consequent possibility of requiring an increased degree of treatment from plants only recently placed in operation.

River regulation, which includes the regulation and control of stream flow as well as pollution, has been effective on the Androscoggin River in Maine. To be successful it appears that the regulatory authority must not only possess outstanding technical competence and integrity, but also must enjoy the respect and confidence of everyone on the river basin. Under such conditions it may be possible to use practically all of the assimilating capacity of the stream with little or no reserve for contingencies or for new sources of pollution.

The water pollution control authorities often determine, on the basis of their best judgment, the reasonable amount of the stream's capacity to accept pollution that shall be allocated to a particular contributor. Should an upstream contributor be permitted to reduce the stream's capacity to accept pollution to a point close to the established standard, the law may not be violated; however, the immediate downstream contributor is deprived of the same rights as his upstream neighbor. As a result, the upstream contributor may be required to afford little or no treatment, whereas his downstream neighbor must afford a high degree because the stream has no further capacity to accept any waste without violating the established standard. The control authority frequently uses its judgment and indicates the degree of treatment that should be given to be equitable, and to reserve for further contributors yet to come some part of the stream's capacity to carry away wastes.

The control authority will usually wish to provide a factor of safety for unknowns, unexpected peak loads, or, perhaps, unusual droughts. The approving agency, therefore, must use considerable engineering judgment to determine the adequacy of the facilities proposed.

Some of the factors which go into the safety margin are as follows:

1. The critical stream flow.
2. The unexpected peak contributions.
3. A reserve assimilating capacity for future contributors.

Factors of Safety

Consider the first of the three items: namely, the critical stream flow. There is hardly justification for considering the worst conditions that ever occur. This is recognized as a subject which has long been within the purview of pollution control authorities. Frequency of both minimum and flood flows has been used as an argument in many engineering projects. When considering the amount of dilution required or the speed with which the stream will carry biochemical oxygen demand to a critical area, it is recognized that these can be computed on the basis of how frequently one is willing to accept unsatisfactory conditions.

Is it now unrealistic to say that design should be for conditions which may occur only once in 500 or 1,000 years? Just as when storm drains are designed with a knowledge that they may be surcharged periodically, engineering judgment is used to provide that a sparsely developed residential area is designed for an occasional surcharge, whereas the frequency of surcharge in the densely developed business and warehouse areas where damaged stock stored in cellars or other potential losses warrants design for but infrequent surcharge. Can the dilution factor be approached in the same manner and, after study of the stream flow characteristics, the frequency be determined of violation of acceptable dilution or nuisance? These factors can be reduced to numbers and a plea is made for the full use of all of the known tools on which to base engineering judgment.

It will be well to evaluate the damage in these critical periods. If a highly industrialized stream is being considered in an area used exclusively for industry, might it not be possible to accept a condition of zero dissolved oxygen that might occur on occasion—say, for example, once in 20 years. The conservationists unquestionably will object to a fish kill even once in 20 years; however, consideration must be given to a balance of economics on the one hand and the benefits derived on the other. If designs are made on the basis of the worst conditions that may occur once in 100 or 500 years, the public as a whole may be committed to impractical expenditures.

The second item is extremely difficult to evaluate. The character of the potential pollutant and the resultant economic loss when an unexpected peak load occurs, must be weighed. The possibility of placing the responsibility for damages should also be considered.

Referring to the third item: namely, the reserve capacity for future contributors. This has been one of the most difficult factors to establish. However, the time is ap-

proaching when this factor can be attacked in a rational manner.

Many are convinced that the full capacity of a stream cannot properly be usurped by any single contributor or group of contributors. The first consideration will be to make some reasonable determination of the percentage of the stream's capacity to assimilate a particular type of pollution, which should be reserved for future contributors. Undoubtedly, the type of stream, the type of development along the stream, the uses to which the stream is being put, the density of development, the proximity to other areas, the expectations for the future of each of these factors, and the confluence of other streams, all influence the determination of the percentage of the stream's ability to assimilate, which should be reserved.

Reserve for Future Pollution

No suggestion is made as to the numerical amount of the stream's capacity to assimilate pollution that shall be reserved for future contributors. Some feel that 40 per cent is far too high and that the reserve should be only 20 or 10 or 5 per cent. This is a determination that requires considerable study of the factors just enumerated. For the moment, however, let it be assumed for the sake of this dissertation that 40 per cent of a stream's capacity to assimilate a type of pollution, say oxygen demand, will be reserved for future contributors and 60 per cent will be allocated to the present contributors.

It is suggested that the next contributor be required to install treatment works of such nature that his plant will draw upon the reserve capacity only to the extent of 60 per cent of the amount of the reserve capacity available: namely, 60 per cent of 40 per cent, or 24 per cent of the original capacity to assimilate that which he may discharge, leaving a residual available to future contributors of 40 – 24 per cent, or 16 per cent of the original capacity. The third contributor would have at his disposal 60 per cent of the remaining 16 per cent, or 9.6 per cent, leaving a balance of 6.4 per cent to future contributors.

This is recognizable, of course, as the familiar law of reactions that are directly proportional to the amount of primary material involved. In the field of physics, this first-order reaction or logarithmic progress is evident in the decay of radioactive materials. In the field of pollution control, it is recognized as the form of Phelps' Law on the rate of biochemical oxidation. This first-order reaction is evident to all in pollution control work and is encountered frequently.

This first step leaves an apparent inequality, which requires adjustment. The contributors locating on the stream at a later date may have less stream capacity at their disposal. It is suggested that the approvals or permits be issued for a period of time equal to the useful life of the installation, in addition to the usual limitations of quantity or quality of the effluent. No better way is known of fixing the useful life than by using the period during which its cost is to be amortized. The bonds on municipal treatment works are issued for a period of 20 or 30 years depending upon the state laws, whereas industrial installations are governed by the amortization rate allowed by the Bureau of Internal Revenue for income tax purposes. Three bills have recently been introduced in the House of Representatives to encourage the prevention of water pollution by allowing amounts paid for industrial waste treatment works to be amortized at an accelerated rate for income tax purposes. Each of these bills permits amortization over a period of 60 months or 5 years. It should not be difficult to establish the reasonable useful life of a treatment plant. At the expiration of the permit or approval, the contributor would be called upon to make such additions or modifications in its treatment plant as will restore the stream to the standard of purity first established, which in this hypothetical case was 60 per cent of the stream's capactiy to assimilate a particular type of pollutant.

By this method, an industry proposing to establish a plant on a particular stream would have foreknowledge of the requirements both present and future. It would have knowledge that it must be prepared to install additions, if necessary, at a preestablished time. Thus, there would be a rotating procedure that would assure the maintenance of a reasonable water quality irrespective of the number of contributors, always making allowance for and providing reasonable assimilating capacity for new industries and for a safety factor. The economic balance of the cost of high degree of treatment will function to prevent over-development of a stream.

Economic Balance of Cost

The percentage of the available capacity of a stream to be initially allocated to existing contributors establishes a sort of parity to be maintained following the expiration of each permit. It will require sound engineering judgment in the establishment of this percentage or so-called parity. It may be possible that future thought, study, and new scientific data will permit fixing this percentage by some rational method. There need not be any deterrent, however, to accepting this method because it demands engineering judgment on the part rather than on the larger sphere of the problem. The adoption of this principle would more definitely place contributors on notice regarding the possible need of modifications and improvements to their plants at the expiration of their permits.

This method may be used whether the standards fix water qualities or establish quantitative limits; for, notwithstanding the fact that only a qualitative standard is established, the approving agency must within the confines of its own department have some idea of the quantitative limit necessary to meet the qualitative standards to determine the acceptability of the applicant's proposed treatment works.

In the field of pollution control, there must be alertness to improved methods of analyzing the problems.

R&D

Rate Formulas for Industrial Wastes

Methods of charging for industrial wastes in municipal sewage systems

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ONE METHOD of abating stream pollution by industrial wastes is to discharge the wastes to city sewers for treatment and disposal with domestic sewage. The practice raises two fundamental questions: 1. What untoward effects will industrial wastes have on the operation of a municipal sewage treatment plant? 2. How shall an industry be charged for the treatment of wastes discharged into a city sewer system?

As more and more industries are required to use municipal disposal systems[1] the first problem becomes more important. This fact was indicated by a survey[2] which showed that 100 municipalities, of about 600 reporting from 30 states, experience troubles caused by industrial wastes in municipal sewage treatment works. The second problem (that of charges) has been attacked in four general ways, all of which can be reduced to basic formulas which are presented in this article.

Theory of Sewage Services Charges

Sewage service charges (sometimes termed or misnamed sewer rentals) are now in effect in one-third of the municipalities of this country with populations over 5000[3]. Such charges are based on the theory that persons who use or have the benefit of sewage treatment should be charged for that service in relation to the benefits enjoyed. Application of this theory to industrial wastes is not simple.

Many municipalities favor charging industry for sewage service whether or not the industry uses the sewer system[4]. Others feel that a fundamental basis for charge should be established. Some industries assume that the municipal taxes which they pay as property owners should cover their fair share of the cost of waste disposal. In many cases, this assumption simply is not so.

The sensible approach to the problem of payment is to take into account the matters of usage and of benefit received. On the basis of volume alone, many industries use the sewerage system out of proportion to their assessed valuation, but this is not the only consideration involved. The strength and nature of the waste must be taken into account. Table 1 shows the wide variation in industrial waste as compared to domestic sewage.

Many industries discharge wastes that are difficult to treat, and a municipality must provide special treatment over and above what would be required for domestic sewage. Since industrial wastes generally are stronger per unit volume than domestic wastes, the logic of special charges is apparent. For these reasons, a rate system should be established which measures the use and benefit derived from a sewer system and which charges accordingly[5].

Perhaps a less obvious reason for establishing an equitable rate is to promote good cooperation between industry and municipality. Exorbitant rates to an industry will result in non-cooperation on the part of industry; non-cooperation may take the form of false analysis of waste, failure to ease the burden on the system, and failure to notify the city when unusual conditions occur requiring special steps at the treatment works[6].

What should these special rates cover and how should they be determined? Most authors agree that such charges should cover operational costs, maintenance, and replacements; others favor the inclusion of fixed debt service costs, as well. There are four general methods of determining special charges for industrial wastes and each of these can be reduced to a formula. These are the "Flat Rate Formula," the "Quality-Quantity Formula," the "California Formula," and the "Joint Committee Formula."

Flat Rate Formula

The Flat Rate Formula is based on some cost per unit; i.e., unit of production, floor space, volume of waste, water used, time, or type of industry. The general Flat Rate Formula is:

$$D = (R)\ (N) \qquad (Eq.\ 1)$$

Where D = Charge in Dollars
R = Rate per Unit
N = Number of Units

Examples of the Flat Rate Formula are:[9]

Renton, Wash.—per 100 workers, $2.50 per mo

Kennewick, Wash.—Canneries, food processing plants and grape juice plants, $20.00 per mo

Clarkson, Wash.—Industrial plants, all types, $3.00-5.00 per mo

Chelalis, Wash.—Industrial plants, all types, 50% of water bill ($1.35 per month min.)

Detroit, Mich.[8]—Industrial plants, all types, $0.25 per 1,000 cu. ft. per mo

There are several advantages to using this type of charge. It has the longest precedent and may be more acceptable than any other to the parties concerned. It is easy to calculate and apply. A small city with only one or two industrial plants would find it unprofitable to conduct an extensive survey of industrial washes in order to establish a complex set of rates that would require frequent sampling. They have neither the staff nor the equipment to manage such a method. It is more feasible to determine to which unit the waste is proportional and charge accordingly.

Once the flat rate charge has been established there is no complex bookkeeping, no expensive sampling; the industry reports the necessary information (number of units, etc.), the charge is computed, and a bill is rendered.

The Flat Rate Formula is generally used in the small municipality where simplicity is the keynote. Since the flat rate charge is an approximation, at best, it is simplicity at the expense of accuracy. It neglects the nature of the waste. Flat rates are frequently based on volume, but volume alone does not measure the full

use and benefit obtained by the industry. For example, in Syracuse, N. Y., one industry has a waste with a 5-day B.O.D. of 1,000,000 ppm. That one industry could contribute a small volume but a heavy load on the treatment plant. Volume and B.O.D., likewise are not the complete measure of benefit and use. Suspended solids content and sometimes chlorine demand also must be taken into account.

Quality-Quantity Formula

In an attempt to obtain a more appropriate basis of charge, several large cities have turned to another method of computing rates, one that takes into account both concentration and volume of waste. This is the Quality-Quantity Formula, abbreviated hereafter as the Q-Q Formula. The Q-Q Formula charge is applied to wastes higher in concentration (or volume) than that considered as normal for the municipality—on the theory that these wastes impose operating costs greater than will be paid by taxes or flat rates.

Each municipality desiring to use a Q-Q Formula must develop its own, but all Q-Q Formulas stem from the basic equation, which assumes that real estate taxes and/or flat rate charges pay for fixed costs and for operation costs to treat a normal waste. The general Q-Q Formula is:

$$D = V \times R \qquad (Eq.\ 2)$$

Where D = Charge in dollars at end of billing period

V = Volume of waste discharged during billing period, expressed in units of 1000 gal, 1000 cu ft, mil gal, etc.

R = Rate in dollars per unit volume based on constituent concentration

$$\text{and } R = f[aP_1(S_t - S_n) + bP_2(O_t - O_n) + cP_3(C_t - C_n) + xP_4(Y_t - Y_n)] \qquad (Eq.\ 3)$$

where S_t = ppm suspended solids in waste

O_t = ppm B.O.D. (5 day) of waste

C_t = ppm chlorine demand of waste

Y_t = ppm of other constituent

f = factor to convert ppm to lb per unit volume

a, b, c, x = factors ranging from 0.0 to 1.0 depending on local conditions and percentage of constituent excess, above a standard, for which charge is to be made.

S_n, O_n, C_n, Y_n = Standard or maximum values respectively of suspended solids, B.O.D., chlorine required and other constituents, for which no special charge is to be made above a flat rate.

TABLE 1
Comparison of Industrial Waste and Domestic Sewage

Industry	Unit of Production	Volume		5 Day B.O.D.		Suspended Solids	
		Gal. per Unit	Pop. Equiv. per Unit[1]	lb. per Unit	Pop. Equiv. per Unit[2]	lb. per Unit	Pop. Equiv. per Unit[3]
Domestic Sewage	Per Capita Per Day	127	1.0	0.17	1.0	0.2	1.0
Oil Refining	100 bbl Crude Oil	77,000	606	12.8	75.5	32.1	160
Canning Tomatoes	100 Cases No. 2 Cans	750	5.9	25.0	147	12.5	62.5
Wool Scouring	100 lb of Goods	125	1.0	9.7	57	7.6	38
Paper Mill	1 Ton of Paper	39,000	307	6.2	36.4	147	73.5

[1] Avg. per cap flow = 127 gpd.

[2] Avg. per cap B.O.D. = 0.17 16 per day.

[3] Avg. per cap susp. sol = 0.2 16 lb per day.

P_1, P_2, P_3, P_4 = Operating costs in cents per lb for handling, treating or disposing, of respectively, suspended solids, B.O.D., chlorine required, and other constituent. Handling, treating and disposing costs may include direct operating costs, overhead, fixed costs, taxes paid by industry, etc.

If costs are based on ppm, the factor "f" is eliminated. The factors a, b, c, x, will include such considerations as the amount of constituent removed, type of treatment, etc. Factors P_1, P_2, P_3, P_4 each will include considerations of cost of power, chemicals, labor, operation, overhead, etc. and may be varied from year to year as operating costs change.

If taxes are assumed to pay for a certain allowable quantity of wastes and special charges are made only for volumes in excess of that quantity, then the basic Q-Q Formula becomes:

$$D = (V_t - V_n) \times R \qquad (Eq.\ 4)$$

where V_t = Vol. of waste

V_n = Vol. allowed without special charge

The values of waste volume and strength may be determined by tests and analyses regularly, periodically, or from single observations. The values of "standard" strengths, below which no special charge is made, may be set arbitrarily or determined from average analyses of the normal dry weather flow of domestic sewage of the community.

The "Buffalo" Formula

The first Q-Q Formula used in this country, generally called the "Buffalo" formula, was developed by Symons and Crane in 1942[9]. Only primary treatment and disinfection are used at the Buffalo sewage treatment plant, and B.O.D. removal is not important because of the dilution provided by the Niagara River. Therefore, this formula contains only the factors of suspended solids and chlorine required, as follows:

$$R = f[P_3(C_t - C_n) + P_1(S_t - S_n)] \qquad (Eq.\ 5)$$

Where R = Rate of special charge in cents/1000 cu ft of waste volume.

P_3 = Contract price of chlorine, cents/lb.

C_n = Normal dry weather chlorine demand (ppm) of raw sewage received at treatment works (5.6 ppm).

P_1 = Cost in cents of chemicals for sludge conditioning and of power for solids disposal resulting from 1 lb. of suspended solids received in raw sewage at treatment works. (This factor includes consideration of suspended solids actually removed.)

S_n = Normal grit-free suspended solids of raw sewage as received at treatment works, (157 ppm)

f, C_t and S_t are as defined under the basic formula.

The factor P_3 may vary from year to year according to the contract price for chlorine; and the factor P_1 may vary according to the price of chemicals and power involved in the disposal of solids, as determined from operations for the previous year or previous two years. The values "C_t" and "S_t" may be established by analysis (periodic or otherwise) to obtain average concentrations to be

applied for any length of time. In this formula, "a" and "c" are unity, and "b" and "x" are zero.

The special charges amounted to 0.136 cents for each ppm of chlorine demand, and 0.00305 cents for each ppm of suspended solids content, both per 1000 cu. ft. of waste produced. When the charge was less than one cent per 1000 cu. ft., it was neglected. Such factors as the effect of dilution or the possible reaction of an industrial waste with the normal sewage were neglected when the formula was derived but have since been applied.

New Brunswick Usage

Another application of this Q-Q Formula is that used at New Brunswick, N. J.,[10] where

$$D = V[22 + 8.34\ (0.0025\ S_t + 0.05\ C_t)] \qquad (Eq.\ 6)$$

where V = Volume in million gallons
S_t = ppm of suspended solids (or sludge)
C_t = ppm of chlorine demand
0.0025 = cents per pound of solids
0.05 = cents per pound of chlorine demand
22 = dollars per million gallons
8.34 = f = factor to convert ppm to lb. per mil gal

In practice this formula reduces simply to:

D = $22 per mil gal—$5 per ton of sludge—$5 per 100 lb. of chlorine demand.

These charges cover only operational costs; the industries must be prepared to pay their share of any costs of plant enlargement.

Dr. Wright's Formulas

A variation of the general Q-Q Formula sets up a basic rate per unit volume (R_b) and multiplies this rate by a factor (K) based on constituent concentration wherein the constituent values, designations, and subscripts are the same as given in Equation 3 and

$$D = V \times K R_b \qquad (Eq.\ 7)$$

Formulas of this type were proposed by Dr. S. R. Wright[11], Head, Civil Engineering Department, University of Texas. In the Wright formulas, if primary treatment alone exists, the charge is based on suspended solids content only; Factors "b, c and x" in the basic formula (Eq. 3) are zero. If primary treatment and chlorination are used, as in Buffalo, the formula includes suspended solids content and chlorine demand, and if complete treatment exists, a charge for 5-day B.O.D. is added.

Dr. Wright assumes that only 50 per cent of the suspended solids content will be removed in a plant so factor "a" in the basic formula becomes 0.5. This type of formula applies for wastes with either excessive or deficient amounts of suspended solids content.

Dr. Wright arbitrarily sets the "standard" constituent values at 150 ppm for suspended solids and 200 ppm for B.O.D., and he gathers cost data into a single factor "R_1" which he terms the ratio of the annual cost of treatment to the annual cost of the entire system.

For primary treatment alone, the Wright formula becomes

$$K = [1 + 0.5\ R_1 \frac{(S_t - 150)}{150}] \qquad (Eq.\ 8)$$

For complete treatment without chlorination, allowing that one-third of the B.O.D. is removed by primary treatment, Dr. Wright's formula is

$$K = 1 + 0.5\ R_1 \frac{(S_t - 150)}{150} + R_1 \frac{(B.O.D. - 200)}{300} \qquad (Eq.\ 9)$$

Allegheny County Formula

A more complex Q-Q Formula of the $D = V \times KR_b$ type is the Allegheny County formula[12]. The County charges a step-wise flat rate for all wastes except those which exceed the arbitrary "standard waste." The standard waste has a suspended solids content of 275 ppm, a 5-day B.O.D. of 300 ppm, and a certain chlorine demand standard, (undetermined at the time of writing). Reduced to an equation the Allegheny formula becomes:

$$K = 1 + R_a[0.75(S_t - S_s)/S_s + 0.25(O_t - O_s)/O_s + fP_s\ (C_t - C_s)] \qquad (Eq.\ 10)$$

where R_a = Ratio of Quality Cost to Total Annual Cost = 0.15
S_s = Avg. suspended solids of all sewage (275 ppm)
O_s = Avg. B.O.D. of all sewage (300 ppm)
C_s = Avg. chlorine demand of all sewage (?)
P_s = Contract price of chlorine in cents per pound.
All other terms are as defined under the general formula.

Belleville, Ill., Application

Another Q-Q Formula of the $D = V \times KR_b$ type is that adopted by Belleville, Ill.,[13] where the premise is that waste production is exactly proportional to water usage as long as the waste does not exceed 200 ppm of B.O.D. In this formula, charges are made on a step-wise percentage of the water bill, with an extra charge made for wastes exceeding 200 ppm B.O.D. The formula reduces to:

$$D = [1 + 0.002(O_t - 200)]R_b \qquad (Eq.\ 11)$$

where D = Charge per 100 cu ft of water used
R_b = Basic rate per 100 cu ft of water used
O_t = ppm B.O.D. of waste

Additional Q-Q Formulas

Since these several various applications of the Q-Q Formula were first summarized and reviewed in WATER & SEWAGE WORKS in April, 1951[14] some 26 additional communities have adopted some form of the Q-Q Formula. They apply this to industrial wastes which are higher in quantity and in concentration, and which cost more to treat than diluted industrial wastes which are less costly to treat. One example is Madison, Wis., where users pay 20 to 50 per cent as a surcharge above the normal bill if the sewage contains a specified degree of pollution; the pollution is measured in terms of stated chemical and bacteriological factors.

The Q-Q Formula method of determining a sewer service charge will give a municipality a fairly accurate picture of how much use and benefit a particular industry is receiving from the sewer system and therefore what the charge should be.

Advantages and Disadvantages

Advantages of the Q-Q Formula are that once an equitable formula for a particular district has been developed, it is easy to apply; the charge can be computed with reasonable accuracy for each industry; and its equitable application promotes good municipality-industry cooperation. Samples are taken of industrial plant effluent, the necessary tests run, the formula applied, the charges computed, and a bill rendered.

One disadvantage of the Q-Q Formula is the problem of developing the formula on an equitable basis. Decisions must be made as follows:

1. What should be the value of the factors a, b, c, x?

2. What strength waste should be taken as a standard: the average strength at the sewage works, as at Buffalo where it includes all industrial wastes in the sewage plus domestic wastes; the average strength of domestic sewage alone; or some arbitrary strength, as in the Allegheny County equation?

3. Should the price of chlorine and

other chemicals and other specific items be included?

4. How often should samples be taken?

5. How often should the factors be reviewed?

These are questions that must be answered by the local engineer.

A second disadvantage is that Q-Q Formula applies only to one region. An equation derived for one city can not be applied in another. Each locality must develop its own equation, an unfortunate situation since many municipalities may not have the talent required to obtain an equitable formula.

A third disadvantage is the large amount of sampling and testing that must be done to supply the data needed for the computation of charges.

In spite of the disadvantages, the Q-Q Formula method has its place: a city that can afford the technicians needed for the required sampling and testing is likely to have an engineering staff that can assemble the amount of data connected with deriving a formula.

California Formula

In an effort to overcome one inherent fault of the Q-Q Formulas, that of being for local application only, the California Sewage Works Assn.[15] recommends that each municipality examine the Flat Rate and Q-Q Formulas and apply the formula most appropriate.

If neither formula seems applicable, two alternatives are suggested. Either no charges are made, or a formula can be used that charges for the additional cost of treatment of the industrial waste while taking into account any taxes paid. Thus the municipality has four possible approaches to its problem of establishing an industrial waste rate.

The combined consideration of cost of treating the waste and of taxes paid produces the "California Formula," as follows:

$$D = M - (S - s) = M - S(1 - t/T) \qquad (Eq.\ 12)$$

where D = Extra cost assessed to industry
T = All taxes paid to municipality, exclusive of industry
t = Taxes paid by industry
S = Cost of operating sewage works, before industry contributes waste, paid by T
s = Industry's share of sewage operation costs, without industrial wastes added, paid by t and s = St/T
M = Cost of operating sewage works with industrial wastes added.

Joint Committee Formula

A fourth method has been devised for the computation of sewage service rates; it is known as the Joint Committee Formula, hereafter abbreviated as the "J-C Formula." This was developed by a Joint Group of 24 members, consisting basically of committees of the American Society of Civil Engineers and of the Section of the Municipal Law of the American Bar Association, with representation of six other organizations including the Federation of Sewage and Industrial Waste Assns.[16,17]

The basic difference between the J-C Formula and other formulas for raising annual revenues is that the Joint Committee believed it unfair to charge only users for the entire cost, which is a fundamental tenet of Flat Rate, Q-Q, or California formulas. The Joint Committee theory is to charge some of the costs to non-users, i.e. property.

To quote from the Committee report, "The needed total annual revenue of a water or sewage works shall be contributed by users and non-users (or by users and properties) for whose use, need, and benefit the facilities of the works were provided, approximately in proportion to the cost of providing the use and the benefits of the works."

The charges are computed as follows: The sewage works system is divided into two parts: 1. collection system and 2. treatment plant. The revenue requirements for these units are also divided in two parts: 1. operation, maintenance, and replacement costs, and 2. fixed charges. The proportion of these two costs to be borne by users and by properties must be determined for each part of the system (collection and treatment). Surface and subsurface drainage is chargeable to property since it has no relation to use. Also provision for future capacity in any element of the system is charged to property since the additional capacity is provided to allow the development of the property. This charge will decrease and become zero as the design date of the structure is reached. When the total charge to properties has been determined, it is possible to derive a schedule of tax rates based on area, front footage, or assessed valuation, that will supply the revenue needed.

Costs chargeable to users for the collection system and treatment plant are determined from a consideration of the design factors of the structures and equipment used. In short, these design factors consider how much of each structure or equipment is necessary for treatment of B.O.D., suspended solids, or volume. (It is assumed that the chlorine demand is proportional to the 5-day B.O.D. and is not an additional factor. This is not necessarily true in all cases.)

The total costs chargeable to users for each design factor is determined and a rate schedule for that factor derived. Thus the user's charge for a particular industry is computed on the basis of an analysis of the industrial waste.

To be specific, the method reduces to this formula:

$$D = (F + O) \times (A) + (f + o) \times (V_{is}) \qquad (Eq.\ 13)$$

where D = Charge in dollars
F = Total fixed cost of the sewage works (collection and treatment) chargeable to property divided by the total assessed valuation of the municipality.
O = Total operating, replacement, and maintenance cost of the sewage works chargeable to property divided by the total assessed valuation of the municipality.
A = Assessed valuation of the industry.
f = Total fixed cost of the sewage works per unit volume chargeable to users.
o = Total operating, replacement, and maintenance cost of the sewage works per unit volume chargeable to users.
V_{is} = Volume of waste produced by the industry.

The factors F, O, f, o consist of the following elements:

$$F = \frac{(w)(I) + (x)(B) + (y)(S) + (z)(V)}{\text{Assessed valuation of municipality}}$$

$$O = \frac{(a)(I_s) + (b)(B_s) + (c)(S_s) + (d)(V_s)}{\text{Assessed valuation of municipality}}$$

$$f = \frac{(100-w)(I) + (100-z)(V)}{\text{1000 gal. waste per year}} + \frac{(100-x)(B)}{\text{lb. B.O.D. per year}} \times \frac{\text{lb. B.O.D.}}{\text{1000 gal. waste}} + \left(\frac{(100-y)(S)}{\text{lb. susp. slds. per yr.}} \times \frac{\text{lb. susp. solids}}{\text{1000 gal. of waste}} \right)$$

$$o = \frac{(100-a)(r)(I_s) + (100-d)(V_s)}{\text{1000 gal. of waste per year}} + \left(\frac{(100-b)(B_s)}{\text{lb. B.O.D. per year}} \times \frac{\text{lb. B.O.D.}}{\text{1000 gal. of waste}} \right) \left(\frac{(100-a)(s)(I_s) + (100-c)(S_s)}{\text{lb. of susp. solids per yr.}} \times \frac{\text{lb. of susp. solids}}{\text{1000 gal. of waste}} \right)$$

TABLE 2

A—Fixed Costs

Structure, Equipment or Operation	Total Cost	Portion Affected by Volume	Portion Affected by Suspended Solids	Portion Affected by B.O.D.
	Dollars per Year	Dollars per Year	Dollars per Year	Dollars per Year
Collection System	35,000	35,000		
Main Pump Station:				
Equipment	1,500	1,500		
Structures	1,250	1,250		
Screen and Grit Chamber	1,500	1,000	500	
Prim. Sed. Tanks	4,500	3,500	1,000	
Trickling Filters	30,000	5,000		25,000
Final Sed. Tanks	9,000	4,500		4,500
Recirculation Pumps	750			750
Chlorine Tanks and Equipment	2,000	500		1,500
Dig. Tanks and Vac. Filters	8,000		8,000	
Main Control Building	7,500	2,000	500	5,000
Plant Water Supply	2,500	750	250	1,500
Roads and Grounds	2,500	750	750	1,500
Plumbing and Heating	4,000	1,000	500	2,500
Total	110,000	56,750	11,000	42,250
		—35,000*		
		21,750		

B—Operating, Replacement and Maintenance Costs

Collection System	2,200	1,500	700	
Main Pump Station	9,200	9,200		
Primary Treatment	6,700	3,350	3,350	
Secondary Treatment	13,500	3,500		10,000
Effluent Chlorination	5,200	700		4,500
Sludge Disposal	17,500		17,500	
General	5,000	1,000	3,000	1,000
Supervisory	6,200	950	4,000	1,250
Collection and Billing	5,000	500	3,500	1,000
Total	70,500	20,700	32,050	17,750
		—1,500*	—700*	
		19,200	31,350	

*Collection system

Where

w = Per cent of Collection system (Intercepter Sewer and Lift Stations) fixed cost chargeable to property.

I = Total Collection system fixed cost.

x = Per cent of fixed cost of items affected by B.O.D. where items are structures, equipment, and operations, chargeable to property.

B = Total fixed cost of items affected by B.O.D.

y = Per cent of fixed cost of items affected by Suspended Solids, chargeable to property.

S = Total fixed cost of items affected by Suspended Solids.

z = Per cent of fixed costs of items affected by Volume, chargeable to property.

V = Total fixed cost of items affected by Volume, exclusive of Collection system.

a = Per cent of operating, replacement, and maintenance cost of the Collection system, chargeable to property.

I_1 = Total operating, replacement, and maintenance cost of Collection system.

b = Per cent of operating, replacement, and maintenance cost of items affected by B.O.D., chargeable to property.

B_1 = Total operating, replacement, and maintenance cost of items affected by B.O.D.

c = Per cent of operating, replacement, and maintenance costs of items affected by Suspended Solids, chargeable to property.

S_1 = Total operating, replacement, and maintenance cost of items affected by Suspended Solids, exclusive of Collection system.

d = Per cent of operating, replacement, and maintenance cost of items affected by Volume, chargeable to property.

V_1 = Total operating, replacement, and maintenance cost of items affected by Volume, exclusive of Collection system.

r = Per cent of operating, replacement, and maintenance cost of Collection system affected by Volume, chargeable to users.

s = Per cent of operating, replacement, and maintenance cost of Collection system affected by Suspended Solids, chargeable to users.

Note:

(100 — per cent chargeable to property) = per cent chargeable to users.

To apply the formula, the factors w, x, y, z, a, b, c, d, r, and s must be estimated and each item (i.e. structures, equipment, and operations) in the system must be examined to decide how much of the fixed, operating, replacement, and maintenance costs may be charged against volume, B.O.D. loading, and suspended solids.

J-C Formula Example

In the example illustrated in Table 2 the assessed value of the municipality is assumed to be $20,000,000, the yearly sewage flow 1,370,000,000 gallons (1,370,000 thousand gallons), the yearly B.O.D. load 3,874,000 lb. and the yearly suspended solids load 3,647,000 lb.

The various factors in the formula reduce to:

Estimated	*From Table 2*
w — 64.0%	I — $35,000
x — 28.2%	B — 42,250
y — 31.7%	S — 11,000
z — 40.5%	V — 21,750
a — 60.0%	I_1 — 2,200
b — 30.0%	B_1 — 17,750
c — 30.0%	S_1 — 31,350
d — 40.0%	V_1 — 19,200
r — 79.5%	
s — 20.5%	

Applying these factors to the J-C Formula, the calculation becomes:

$$F = \frac{[(0.64)\ (35{,}000) + (0.282)\ (42{,}250) + (0.317)\ (11{,}000) + (0.405)\ (21{,}750)]}{20{,}000{,}000}$$

= $46,580 per 20,000 = $2.329 per $1000 of assessed valuation.

$$O = \frac{[(0.60)\ (2{,}200) + (0.30)\ (17{,}750) + (0.30)\ (31{,}350) + (0.40)\ (19{,}200)]}{\$20{,}000{,}000}$$

= $23,740 per 20,000 = $1.187 per $1000 of assessed valuation

Total tax rate—$3.516 per $1000 of assessed valuation.

Assume:

300 ppm B.O.D. = 2.5 lb./1000 gal.
250 ppm Susp. Solids = 2.08 lb./1000 gal.

Therefore:

$$f = \frac{[1.00 - 0.64)\ (35{,}000) + (1.000 - 0.405)\ (21{,}750)]}{1{,}370{,}000} + \frac{(1.00 - 0.282)\ (42{,}250)}{3{,}874{,}000} \times 2.5 +$$

$$\frac{(1.00 - 0.317)\,(11{,}000)}{3{,}647{,}000} \times 2.08$$

= $0.0186 per 1000 gal. + $0.0196 per 1000 gal. + $0.0043 per 1000 gal.
= $0.0425 per 1000 gal.

And:

$$o = \left\{\frac{[(1.00 - 0.60)\,(0.795)\,(2{,}200) + (1.00 - 0.40)\,(19{,}200)]}{1{,}370{,}000}\right\} +$$

$$\left\{\frac{(1.00 - 0.30)\,(17{,}570)}{3{,}874{,}000} \times 2.5\right\} +$$

$$\left\{\frac{[(1.00 - 0.60)\,(0.205)\,(2{,}200) + (1.00 - 0.30)\,(31{,}350)]}{3{,}647{,}000} \times 2.08\right\}$$

= $0.0089 per 1000 gal. + $0.0080 per 1000 gal. + $0.0126 per 1000 gal.
= $0.0295 per 1000 gal.

Total volume rate = $0.0425 + $0.0295 = $0.0720 per 1000 gallons of waste produced. Substituting in the original formula:

$$D = (F + O) \times (A) + (f + o) \times (V_{in})$$

$$D = (\$3.516 \text{ per } \$1000) \times (A) + (\$0.0720 \text{ per } 1000 \text{ gal.}) \times (V_{in})$$

Where:

A = Assessed valuation of the industry
V_{in} = Volume of industrial waste produced.

Advantages and Disadvantages

One advantage of the J-C Formula is that it is completely fair. It examines each component of the sewer system and treatment works critically and determines what portion of its fixed costs, operational costs, and maintenance costs should be charged to the various categories. The cost of future capacity is added and reduced periodically as the design date of the structure is approached. The J-C Formula is most equitable and it should appeal both to municipalities and industry.

Disadvantages of the J-C Formula are the exacting method with which each structure must be examined, the decisions that must be made in relation to the percentage of each item to be charged to each category, the bookkeeping involved to determine a rate for tax assessment and a rate for volume, the 5-day B.O.D. load, the suspended solids content, and other factors.

After the rates have been established, the sampling necessary to maintain the procedure is expensive. The cost may be as high as $40 to $80 per day of sampling and testing. Two days of sampling and testing per year (taken as a minimum) might cost the city 30 per cent of the assessed charge for some small industries.

The Joint Committee suggests a remedy. Assuming two days of sampling and testing as a minimum, and a cost of five per cent of the yearly income from industry as a maximum, a "standard waste" may be established below which no sampling will be done. The standard may be set as a certain volume per day, a certain suspended solids content, or a certain 5-day B.O.D. load, although the latter two might encourage dilution with cooling water to meet the standard. Such a dilution procedure would penalize an industry on a volume basis but perhaps not in the same proportion.

Another problem is the variation of the future capacity factor. If this factor is to be fair it must decrease with the passage of time. This is complicated, however, since the whole sewerage system must be reviewed each time a change is to be made. Three to ten year intervals have been suggested for review, depending on the growth of the community. Once the basic facts are at hand, however, complications can be kept at a minimum.

The J-C Formula is more difficult to administer than the Q-Q Formula, but has its place, particularly in the large industrial city which has staff and money available and which needs an accurate method of charging industry for use and benefit of the sewage works system. Obviously the J-C Formula is more accurate than the flat rate or Q-Q formulas.

Summary

The problem of disposal of industrial wastes is growing so rapidly that if treatment in the municipal plant is the answer, as it seems to be, industries should be charged for the use and benefit derived from the municipal sewage system.

Several formulas are available for determining equitable charges. Each has its specialized realm of application: The Flat Rate Formula in small municipalities with very few industries; the Q-Q Formula in larger cities, needing a more accurate charge basis due to more industries and more complex wastes; and the California Formula or the J-C Formula in large industrial cities where accurate and equitable charge bases are essential.

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Ed. Note: For a complete discussion of waste disposal charges, the reader is referred to the 81-page Special Report 18S, "Industrial Waste Disposal Charges in Cities Over 5000 Population," published by The Am. Pub. Wks. Assn., 1313 E. 60th St., Chicago 37, Ill.

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C-405-1

Sewer System Operation and Maintenance*

by LLOYD D. KNAPP

City Engineer, Milwaukee, Wis.

THE Bureau of Sewers designs, constructs, operates and maintains all combined, sanitary and storm sewers in the City of Milwaukee. All house sewers, from the main sewer to the building, are the property and responsibility of the property owner, and must be cleaned and maintained by him. The Milwaukee Sewerage Commission designs, constructs, operates and maintains intercepting sewers and a sewage treatment plant for the entire metropolitan area. The Commission was organized in 1913. Prior to that time all sewers in the City were of the combined type and emptied directly into one of the three rivers or into Lake Michigan.

Since 1915, the city has constructed separate sanitary and storm sewers in its newly annexed territories. Today the Bureau is responsible for approximately 500 miles of combined sewers, 300 miles of sanitary sewers and 300 miles of storm sewers. These sewers, most of which are circular, range in size from 6 in. to 144 in. diameter. Some of the storm sewers are of a rectangular section, the largest of which is a double box, with each side measuring 7 ft. by 10 ft.

The older sewers were built of clay pipe, natural cement concrete pipe and brick. The natural cement concrete pipe sewers were either 12 in. diameter circular, or egg-shaped 12 in. by 18 in., or 15 in. by 21 in., with a flat base to facilitate laying. Most of the older sewers 24 in. diameter or larger were built of brick, and in few instances of planks. Today vitrified clay pipe is used in sizes up to 36 in. diameter, concrete pipe in sizes up to 66 in. diameter, and monolithic concrete for box sections and circular sections as small as 48 in. diameter. Vitrified clay liner plates are used where needed in the monolithic sewers and in pipe sewers 42 in. diameter and over.

It is present policy to use concrete pipe for sanitary and combined sewers in residential and local business areas, and to use vitrified clay pipe in light manufacturing and industrial districts. Zoning is quite well stabilized, and this policy has proven satisfactory over a long period of years. The sewers are quite well ventilated and, since the establishment of the Sewerage Commission, designs have provided for minimum velocities of 2 ft. per second. There are, therefore, but few septic conditions, and there has been no known trouble with hydrogen sulfide gas in the residential areas.

Organization

The Bureau of Sewers is organized into a construction division, an engineering or design division, an accounting division, and a maintenance diivsion. This latter division is in charge of the cleaning, flushing and repair of all sewers and appurtenances, as well as the construction of all catch basins, storm inlets and overflows. The division is under the direct charge of a field supervisor and an assistant. The city is divided into three districts, each under the supervision of a district foreman reporting to the field supervisor. Each district foreman is in charge of two or three construction gangs, consisting of a foreman with eight or ten men, a catch basin cleaning crew, one or two sewer cleaning gangs, a flushing crew, one or two sewer masons with helpers, a troubleman, and a timekeeper. At division headquarters there is a blacksmith, a carpenter, and a machinist, all with helpers, and two sewer examining crews of three men each.

All city-owned automotive equipment, such as automobiles, trucks, trailers, air compressors, eductors, concrete mixers, cranes, etc., are operated and maintained by the Bureau of Municipal Equipment. This equipment is rented to the various other bureaus as needed and at rates somewhat below that charged by private owners. Special equipment such as pumps, cleaning machines, steamers, etc., are in direct charge of the Bureau of Sewers.

Construction Crews

The construction crews excavate for the catch basins, and construct storm inlets and overflows during the construction seasons. These crews also build short sections of new sewers as the occasion may require.

Catch basin and manhole bottoms are poured with ready-mixed concrete and, where conditions permit, steel forms are set up and the bottom half of the catch basin is also poured with ready-mixed concrete. A sandbag is placed in the form to provide an opening for the overflow pipe and trap. A sewer mason follows this crew and lays up the top half of the catch basin with concrete brick.

The storm inlet assembly consists of a frame and grate with a side inlet box resting on a layer of brick. The brick rests on the edge of a large cast iron bowl, and the bowl in turn rests on a cast iron elbow with a 15-in. radius. The elbow has a large flat base to facilitate placement, and after it has been set and backfilled with gravel, the rest of the assembly is quickly put together. The frames, grates, and side inlet boxes used in storm inlet construction are identical with the castings used for catch basins.

Each crew has a combination tool wagon and shanty equipped with a small stove. Each crew is assigned an air compressor with sufficient capacity to operate two jack hammers continuously. The city owns both trailer-mounted and truck-mounted compressors and an effort is made to keep one truck-mounted compressor in each district for emergency use. The older compressors are mostly Sullivan or Ingersoll Rand, while the newer machines are LeRoi. Each crew also has two jack hammers, two clay diggers, and a demolition tool. This latter tool is a small compact rig that can be used inside a catch basin or manhole for tearing out masonry work. These pneumatic tools are of various makes such as Sullivan, Cleveland, Ingersoll Rand, and Chicago Pneumatic. All of the pneumatic equipment has proven satisfactory.

Each construction crew also has a 1½-in. C. H. & E. centrifugal pump, two wheelbarrows, screw jacks, 200 ft. of 2½-in. flushing hose, 100 ft. of 1-in. flushing hose, a hydrant valve, barricades, red flags, lanterns, and miscellaneous small tools. These special hydrant valves are used to regulate the flow of water, thus permitting the hydrant itself to be open to full capacity. The Water Department recommends this practice as a means of preventing wear and tear on the hydrant parts.

The city owns one truck-mounted Hydro-crane with a ¼-cu. yd. bucket, which the Bureau of Sewers uses on a year-around basis. One or two more of these cranes are rented during the construction season. These cranes are operated hydraulically, even to the opening and closing of the bucket. They are used for digging purposes, and they operate quite successfully where the ground is not too hard.

The advantages of this type of machine are that it can be quickly moved from place to place in an emergency and can be digging 2 or 3 minutes after arrival on the job. The machine is mounted on an International Truck chassis and can travel

LE ROI 105-160 cu ft per min. two stage compressor on International truck.

*Reprinted from Sew. Wks. Jour., Vol. 21, p. 475 by permission.

SEWER CLEANING MACHINE with self-closing bucket (Turbine Sewer Machine Co.)

along city streets safely at a speed of 25 to 30 miles per hour. This equipment is used to greatest advantage in the outskirts where there is little interference from other underground structures. One 2½-cu. yd. dump truck accompanies each Hydro-crane. This is sufficient, especially in the outskirts where a dump can usually be found within a 5- or 10-minute run. These cranes are also used in the older sections of the city, at locations where digging conditions are favorable. Experience with the Hydro-cranes to date indicates that under favorable conditions the cost of excavation can be reduced approximately 30 per cent over hand digging.

Otherwise all digging for catch basin and overflow construction as well as for sewer repairs is done by hand. The hand digging crews load their dirt into trailers of about 5 cu. yd. capacity. The empties are spotted and loads pulled once a day.

In the winter months the construction crews are put out on repair jobs. They remove and replace broken or cracked pipe, break out and replace defective concrete in tunnels, and break out defective masonry in the brick sewers preparatory to repairs to be made by the sewer masons. One extensive repair job carried over several winter seasons, involving the removal and replacement of concrete in the lower quadrant of a 72-in. tunnel and the lining of same with vitrified clay liner plates. This was a storm sewer tunnel into which acid had been discharged for several years. Winter digging is admittedly expensive, but it has been necessary to operate all winter in order to keep the crews manned with experienced men, and because it is not possible to hire sufficient men to make the necessary repairs in the summer months when the construction program is heavy. Then too, it would be difficult to secure the extra tools and equipment needed to do both repairs and construction in the summer.

The city of Milwaukee for years has had an Accident Prevention Committee composed of key representatives of the various operating departments. The field supervisor is the representative for the Bureau. This committee has done much to promote safety among city employees. Supervisory forces make it a point to instruct new men in the use of tools, to examine tools for defects, etc. Supervisors are especially particular in the bracing and shoring of trenches and tunnel sections. Men are not permitted to work in the so-called "rat hole" sections. As a result of these precautions the usual accidents are of a minor nature. There have been no accidents due to cave-ins for many years.

Sewer Cleaning

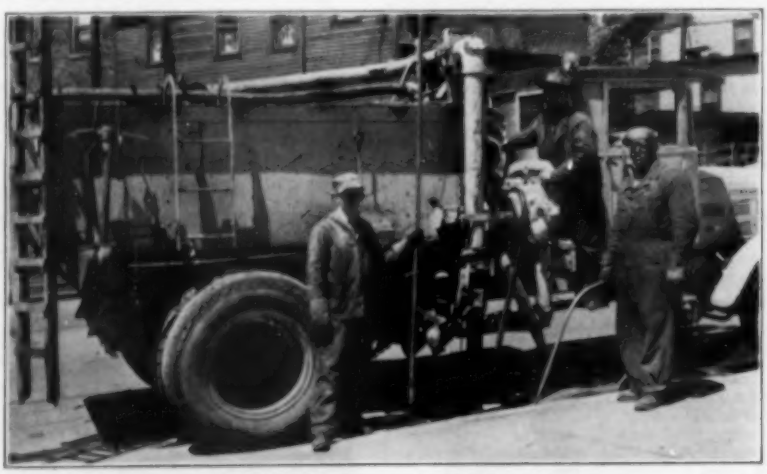
There are four sewer cleaning crews of three men each. One crew is using a pair of Champion 7.5-h.p. machines; while two crews are using a pair of Sewer Turbine 7.5-h.p. machines. One crew has a pair of 3-h.p. Sewer Turbine machines. The smaller machines are used on the smaller sewers so as not to overload the motors. All of the machines are proving satisfactory. However, the level winding apparatus was removed from the Champion machines and substituted by a loose pulley. The gearing on the Turbine machines was also changed so as to increase the cable speed from 33 to 90 ft. per minute. Self-closing buckets are used in sizes from 6 in. to 18 in., made by the Champion Company. Some plain buckets or scoops have been made up to fit several different sizes of small egg-shaped sewers, and circular scoops have been made for sewers 21 in. diameter or larger.

Elm strips ½ in. by 2 in. and of varying lengths up to 10 or 12 ft. are used in getting the pilot cables through the sewer. These strips are notched at the ends and fastened together with wire. They are quite flexible and can be readily shoved through the sewer. Any water in the sewer, of course, will cause the strips to float and facilitates their use. If the normal flow in the sewer is not sufficient to float the strips it is an easy matter to connect a hose to the nearest hydrant and obtain the amount of water desired. Jointed, wooden sewer rods about 1¼ in. square and in 3-ft. lengths are used for the same purpose. When neither the elm strips or rods will work, a Flexible sewer rod is put through and the pilot cable pulled back when the rod is withdrawn.

Sewers under busy streets or car tracks are cleaned at night. When cleaning along car tracks, hand cleaning rigs are employed, as these can be shoved aside more readily than the power machines in order to let street cars pass.

Flushing

Four flushing crews of three men each are maintained. Each crew is equipped with about 500 ft. of 2½-in. hose, one 8-in. and one 12-in. flushing bag, a wheelbarrow, manhole guards and various small tools. During the winter a stiff rubber coated hose is used, from which the water can be drained and which will not freeze up during severe cold. In the warmer months discarded fire hose is employed, which is bought from the Fire Department for 10 cents a foot. One length of the rubber covered hose is shoved down the manhole and into the sewer because of ease of handling. Hose bridges are made by a carpenter and consist of cham-



ELGIN EDUCTOR mounted on Sterling chassis
Note agitator pipe and long handled rake for cleaning out sticks

fered 3-in. planks fastened together with steel bands. Discarded rubber hose is cut up and nailed on the bottom of the planks and this prevents skidding of the hose bridge under impact of even heavy vehicles, provided they travel at moderate speed. During 1947, 262 miles of sewers were flushed.

All storm inlets are flushed once a year by these same crews. There is a considerable waste of time in coupling up hose to the nearest hydrant, setting the hose bridges, etc., only to find that one good shot of water is all that is needed. The field supervisor is now studying the possibilities of using power flushers for this work.

Catch Basin Cleaning

Catch basins are cleaned once a year. This work is carried out by two catch basin cleaning crews, each consisting of a foreman and eight to ten men. Each crew has three or four Elgin eductors, a 1½-ton truck, a wheelbarrow, a small centrifugal pump and various miscellaneous tools. Each educator crew will clean an average of twenty catch basins per day. The truck and two men are used to clean, by hand, those basins which are inaccessible to the eductors, and to finish cleaning those basins which cannot be properly cleaned by the eductors. Each eductor crew carries a garden rake for removing sticks, branches, etc. They frequently find chunks of broken concrete or other material which cannot be removed either by the eductor or by the rake, and the extra cleaning is then taken care of by this manual cleaning gang. The eductors are over 20 years old and are in need of replacement. It is hoped soon to inaugurate a program of modern equipment replacements.

The eductors operate about 8 months of the year, which is about all that weather conditions will permit. During the winter months the crews do hand cleaning of catch basins.

Last year 19,262 catch basins were cleaned by eductor and 5,099 by hand. Admittedly hand cleaning is more expensive, but there will always be many catch basins that cannot be cleaned with the present equipment. And, invariably, either weather conditions or appropriations for equipment rental will interfere before the complete rounds can be made of all catch basin cleaning work. There are approximately 25,000 catch basins and 15,000 storm inlets. The inlets are taken care of, as previously mentioned, by the flushing crews.

BUCYRUS-ERIE H-2 Hydrocrane mounted on International truck chassis
with orange peel bucket for cleaning catch basins

The foreman is furnished with blue line prints of quarter-sections showing the location of all catch basins and storm inlets. He returns these maps to headquarters showing the date of cleaning and notes as to the structural condition of the basins.

Sewer Troublemen

Each district has a sewer troubleman who drives a pick-up truck. His duty is to investigate all complaints in his district. These complaints cover a wide range of subjects, from water standing in the gutter to a leaking kitchen faucet; from rats crawling out of plumbing fixtures to rubber balls lodged in downspouts. In most cases the Bureau of Sewers is not involved, but the troubleman will give the best advice of which he is capable.

The troubleman opens up blocked sewers and catch basins, calling on the nearest labor gang for help. A troubleman and two laborers are on duty every Saturday, Sunday and holiday to handle emergency calls and one of the troublemen is always subject to call by the City Hall night complaint clerk.

During storms, when hundreds of complaints may come in, various foremen and some of the better class laborers are used on trouble shooting service. At such times the maximum number of crews are operated that can be provided with transportation. These forces stay on the job until every complaint has been investigated. In some instances this has taken as many as 36 hours of continuous operation.

Troublemen are also employed during slack periods with the delivery of small orders of materials for construction crews and the moving of the flushing crews and brickmasons from job to job. They also answers complaints on loose manhole covers. If the cover and frame are found to be in reasonably good condition the cover is sealed in place with Hallemite, which has been giving us good service. All flushing crews carry a small supply of this compound.

HOUGH END LOADER used for cleaning up jobs and loading hand excavated material.

CLEAVER-BROOKS oil burning steamer
for thawing out frozen catch basins, storm inlets and culverts

Sewer Inspection Crews

There are two sewer examining crews consisting of a foreman and two men each. These crews have trained personnel and special equipment, and have regular programs for examining sewers as to structural conditions, amount of flow, depth of deposit, etc. Many sewers are flushed or cleaned in accordance with the information obtained from these reports. When a street is to be repaved, an examining crew inspects the sewers, and the designers use their report to determine the necessity of rebuilding the sewer because of its structural condition.

These crews are used for many types of work. They examine all contract work, upon completion, and discover many defects overlooked by the inspector, or which could not be determined by the inspector working alone. They are used frequently in tracing out the point at which given house services and overflows are connected to the sewer. They check for highwater marks in manholes following storms, and occasionally they make house to house surveys to determine the extent of backwater conditions.

These crews are so valuable that their services are in constant demand by the construction forces, engineering division and also by district foremen. It is difficult to keep them at their primary task of examining sewers on a routine basis.

Examinations of the smaller sewers are made by means of flashlights and mirrors. The men crawl or walk through all sewers 30 in. in diameter or larger, flow conditions permitting, and occasionally crawl through 24-in. sewers.

Each crew has a safety belt for use in deep manholes, rubber coats, hats and boots for ordinary work and rubber suits for very wet, dirty work. They also carry a Wolff safety lamp, aluminum ladders for use where manhole steps are unsafe or missing, a small quantity of potassium permanganate, and a considerable number of small tools and supplies.

Sewer Masons

There are four sewer masons, each with two helpers, who work the year around. During the construction season, when the new catch basin work required in connection with new paving is the heaviest, two or three more mason crews are added to build basins and to set basins and manhole frames to final grade. Because of past budget restrictions it has been necessary to impose on some of the more skilled laborers to do this work without extra pay. This past summer, however, it was possible to obtain for three of the best men the regular sewer mason pay for a period of a few months. A plan is now in development to pay four of the best men a rate $15 per month above that of common labor. These men will be used normally as leading helpers to a sewer mason. In the rush seasons they will be used for setting manholes and catch basins to grade, thus relieving the regular masons for the more skilled work of building manholes and catch basins.

There are more brick repairs than can be handled with the four regular masons during the off season. There are perhaps 25,000 catch basins and approximately 40,000 manholes, most of which are built of brick and many of which need repairs, as well as many, many miles of brick sewers which need more and more repair work as they become older.

At the present time the mason crews have only a small tool box, but a program is planned to equip all crews with a small combination tool wagon and shanty.

Yards

At the district yards there is a supply of special tools and equipment as needed, such as centrifugal pumps up to 4-in. discharge, 4-in. Pemberthy syphon pumps, three Homelite blowers operated by gas engines, two electrically operated blowers, three 1500-watt portable light plants, and a Cleaver Brooks oil-burning steamer for thawing out frozen catch basins. There are small derricks and two hoists operated by compressed air and two operated by gas engines, also flumes of various sizes, rock drills, and cutting and welding equipment. In addition there are three Flexible sewer rod outfits which are used in opening up blocked sewers and Coleman rods for use in checking clogged house sewers.

The clerical forces keep time and material records, order materials and equipment, keep a card index file of complaints by house numbers, type the reports of the examining crews, tabulate the records of cleaning, flushing, etc. Ready-mix concrete, backfill gravel, brick and pipe are purchased on open order and may be secured as needed from the vendor, who delivers directly to the job.

In all there are 160 people in the operation and repair division, which includes all classes from laborers and clerks on up to the field supervisor. Common laborers are known as "city laborers" and do sewer cleaning and flushing and catch basin cleaning. They receive a top pay of $140 per month, plus a cost of living bonus of $83.02 per month. The laborers on construction crews are called "sewer laborers" and receive a top pay of $150 per month, plus the cost of living bonus. Sewer examiners get $165 per month, their foreman and the troublemen get $180 per month, while the construction crew foremen receive $210 per month, all with the cost of living bonus in addition. The highest, of course, is received by the field supervisor, who gets $350 per month and the bonus. The total budget for operation and repairs for 1948 amounted to $529,459, approximately $480 per mile.

TYPICAL flushing crew
Note regulating valve which permits hydrant to be open to full capacity

. . . Save the Cost of Replacing Them!

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. . . restoring them to 95% of original capacity!

Specially designed power rodding, mobile pumping and hydraulic pressure equipment provides NEW cleaning efficiency for clogged water mains.

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These factors keynote the modern water main cleaning methods developed by the NATIONAL POWER RODDING CORPORATION.

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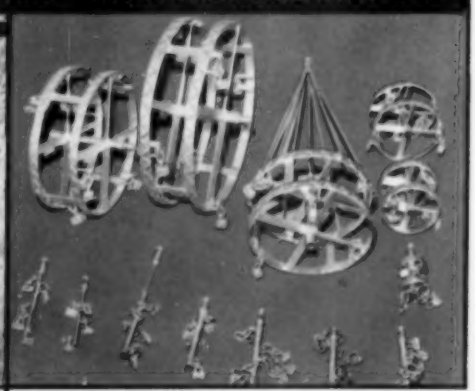
Patented Equipment Makes The Difference—Before using the new mobile pumping unit, this hydraulic power pressure tool is inserted into the pipe. By using new, improved methods the interruption of normal operations are reduced to a minimum. This tool is composed of hundreds of scraping, propelling and polishing blades with cone pushers. The tremendous water pressure behind the tool provides multiple cleaning action guaranteeing to restore the line to 95% of its original capacity. Hydraulic power pressure tools range in size from 4 to 60 inches to take care of a wide size range of mains.

SUBSTANTIAL SAVINGS PLUS 95% WATER MAIN EFFICIENCY RESULT FROM THE COMBINATION

Power Rodding For Water Mains Using New Techniques



Patented equipment developed and used exclusively by the NATIONAL POWER RODDING CORP. cleans mains where extra heavy deposits have formed.

New Method Assures Success—Small, portable machines have been used in the water main cleaning field for many years. Now, through NATIONAL POWER RODDING'S exclusive patented continuous steel rodding equipment, the power method has become the important factor. New truck-mounted equipment cleans mains faster and more efficiently than ever before. Up to 1500 feet of water main can be rebored in one operation; meaning a minimum of disturbance to the community or industry AND a substantial savings of funds.

Engineering Refinements Create Proven Efficiency—The NATIONAL POWER RODDING CORP. safeguards through precision engineering both men and mains. The power-driven cleaning head is completely under mechanical control. No manual force here. When the boring head reaches a seemingly immovable obstruction, the automatic fluid clutch absorbs the shock and the forward action is stopped without damage to the valve seats or fittings and the precision footage indicator automatically records the distance. This simple refinement alone, saves many man-hours in locating the trouble and making repairs. The exclusive mobile rodding unit drives the cleaning heads through mains that, before, would need replacing. These chain head augers and scale drills used in the boring operation are specially tooled for maximum performance.

NATIONAL POWER RODDING CORPORATION

4600 West Madison Street

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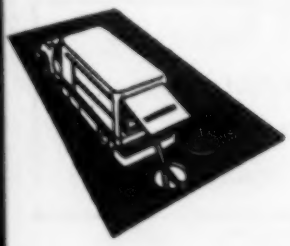

National Power Rodding Corporation

WATER MAIN

Size	Approximate Length	Kind { Cast Iron / Steel }	Probable Contents

Name _____

Title _____

Address _____

City _____ Zone _____ State _____

☐ Send catalog "REBORE WATER MAINS" proving the superiority of the NPRC pipe cleaning system.

☐ Send an engineer for free consultation.

Type of Flow: Pressurized _____ Gravity _____

Transmission Line _____ Distribution Line _____

Average Pressure Now _____

Approximate Age of Pipe _____ Average Pressure Now _____

Location of Pipe: Underpavement _____ Other (please state where) _____

If underground, what is approximate depth? _____

_____

Nothing is more important than your complete satisfaction. This policy, plus courteous service is a matter of pride with our personnel.

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Trained Crews Use Modern Methods — Constant supervision on each job is a day-to-day rule. Trained foremen plan each step using the latest equipment. Power pipe cutters, walkie-talkies, pipe locaters, and night lights represent just a few of the modern tools used by the NATIONAL POWER RODDING CORP. Heavy duty couplings recouple the pipe; curb cocks are sealed to keep muck out of lines in buildings and homes; fire hydrants or blow-off valves are opened to discharge accumulated scrapings. And every step of the operation is handled by crews with years of experience and know-how. This "human" factor is another link in the chain of efficiency and economy.

A JOB WELL DONE—Throughout the course of the water main cleaning, the hydraulic power pressure tool passes through many "tees" and "elbows". Even though the turn may be 90 degrees, the pressure tool, backed by revolutionary new equipment and methods, drives forward removing the sludge and muck in its path. At the predetermined point where the pressure tool leaves the main, an opening is made. Out of this opening passes this corrosion . . . and another water main is brought to maximum efficiency through these new methods.

OF HYDRAULIC PRESSURE AND POWER RODDING TEAMWORK

Investigate Now, No Obligation — If your need is now, or in the future, do not hesitate to contact THE NATIONAL POWER RODDING CORP. We are always more than happy to discuss your problems, make suggestions, give estimates. Many, many times we have found a few simple suggestions from us have saved many thousands of dollars. Our specialists in the field are at your call. Remember . . . preventive action today may eliminate costly emergency repairs tomorrow.

• WRITE • WIRE • CALL COLLECT

Sewer Reboring Service Offered—In addition to the NATIONAL POWER RODDING CORP'S. water main cleaning service, a complete sewer pipe restoring service is offered. Through vast experience and technical know-how coupled with exclusive patented equipment, sewers are cleaned in a minimum of time at much less cost. Before you plan construction of new expansion sewers, investigate the new power rodding method of reboring old lines and restoring them to normal capacity. Contact us for the complete story on our proven revolutionary sewer cleaning method.

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"We had built a new Water Treatment Plant and although the specifications for our high life pumps called for 700 G. P. M. we were only getting 465 G. P. M. I found some of your literature and contacted your firm and I must say you have fully carried out the promises made in your advertising. After cleaning the water mains we are now pumping the 700 G. P. M. that was set out in our specifications."

"The supply line at the time before cleaning was only delivering 240 G.P.M. After cleaning was completed the line delivered 620 G.P.M. and is still doing so at this writing. We cannot speak words for the promptness and efficiency . . . ."

NEW EQUIPMENT FOR MODERN WATER-MAIN CLEANING

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National Power Rodding Corp. Serves Industries, Utilities; Municipalities; Lowering Fire Insurance Rates; Increasing The Coefficient Of The Mains

Nothing Is More Important Than Your Complete Satisfaction. This Policy, Plus Courteous Service, Is A Matter Of Pride With Our Personnel.

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FAIRBANKS-MORSE 4-in. centrifugal Woods trash pump, 20 hp. Le Roi Motor
Capacity 70,000 gph. Used for pumping out sewers, basements, flooded areas, etc.

Discussion

Francis S. Friel
President,
Albright and Friel, Inc., Con. Engrs.,
Philadelphia, Pa.

Mr. Knapp has given an excellent outline of the scope of the organization, equipment and maintenance procedures of the Milwaukee Bureau of Sewers.

In Mr. Knapp's remarks relating to sewer construction he reports that all house sewers from the main sewer to the building are the responsibility of the property owner and must be cleaned and maintained by him. This same practice prevails in the Philadephia area. Prior to the war, one suburban area outside of Philadelphia made house connections through contract, within the bed of the street, and charged the property owners a fixed sum for it. This practice has been stopped because of present labor conditions, and now property owners are required to engage their own contractors who, in turn, must be bonded by the municipality.

Reference is made to the practice in Milwaukee of using vitrified clay pipe for sewer lines up to 36 in. in diameter; concrete pipe up to 66 in. in diameter and monolithic concrete structures with vitrified clay liner plates where needed. It is also interesting to observe that it is the policy in Milwaukee to use concrete pipe for sanitary and combined sewers in residential and local business areas, and to use vitrified clay pipe in light manufacturing and industrial districts. This practice is commended.

Mr. Knapp does not mention any difficulty experienced in locating manholes or other sewer structures. Manholes are often covered with new paving or by grading of private property or regrading of roads, and instruments to locate them are invaluable in time-saving. Magnetic dip needles are convenient for shallow depths, while the "M-scope" is required for deeper coverage.

The use of the sewer examining crews for inspection of new construction and for periodic examination of lines is good practice. The best insurance against excessive maintenance is a well-designed and well-constructed sewer line. A small municipality in Pennsylvania installed a sewer system about 25 years ago. The sewers were poorly constructed due to a lack of proper inspection. Since the original construction, more than twice the first cost has been spent by the town and by W.P.A. in attempting to repair the sewer lines. In some instances, a pipe between two manholes, located less than 300 ft. apart was out of alignment as much as 3 feet. In addition, the system leaked badly. The unsatisfactory conditions in this sanitary sewer system have not been corrected and a large expenditure is still necessary to complete the rectification of the original unsatisfactory work. Money spent for good engineering and inspection pays dividends on future maintenance.

The disintegration of sewers, as indicated by the need for a retreading job on a 72-in. sewer noted in Mr. Knapp's paper, once again illustrates the need and justification for regulation of the disposal of industrial wastes, taking into account the character as well as the volume of the wastes to be handled. In some cities, surveys have been made to eliminate the discharge of industrial wastes, particularly strong acids, which might cause the disintegration of sewer lines. It is certainly logical to require a particular industry to neutralize strong wastes prior to their discharge to a sewer system.

The frequency of cleaning of a sewer line is dictated by the character of sewage, the flatness of the sewer grades, the condition of the pipes themselves and also possibly by weather and climatic conditions. No hard and fast rule can be applied as to the interval between the cleaning of a sewer. In Lower Merion Township, Pa., the sewers are flushed once a year. The conditions observed during the flushing period form the basis of a priority maintenance program. All free time of the maintenance crew is used in a systematic cleaning of the 142 miles of sewers. Six years are required for the complete coverage cycle. A force of four men with one truck and up-to-date cleaning equipment does the job. The superintendent reported recently that only three stoppage complaints have been received in five years.

There are some instances where sewers have never been cleaned since they were installed. On the other hand, certain sewers have clogged in a relatively short period of time due to the growth of tree roots and other external causes.

The use of a flexible steel type of sewer rod to clean sewers has proved advantageous in many places throughout the country. This type of equipment may be used to remove obstructions which cannot be dislodged by a wooden rod. It is especially effective where fire plugs may not be available and when extra flushing

BUCYRUS-ERIE H-3 hydrocrane mounted on International truck chassis
Clam shell bucket for excavating work

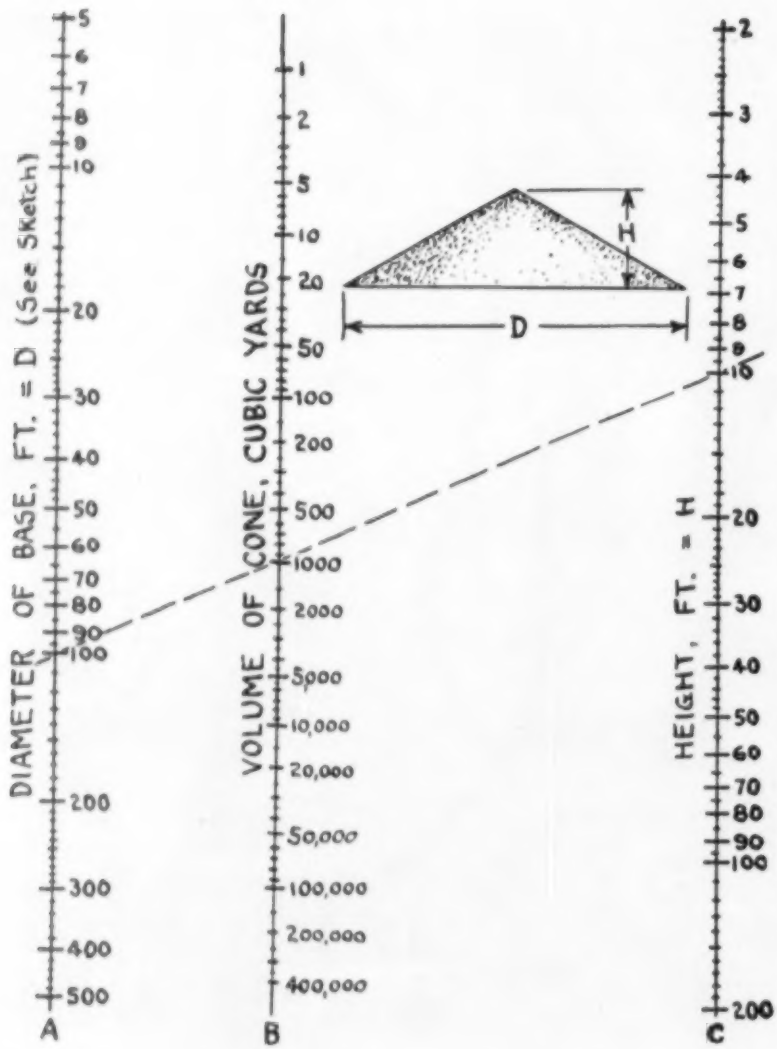
water must be hauled to the work. There also is a safety factor involved in using flexible steel rods, since the men are working above ground.

The mechanical cleaning at Milwaukee is apparently by the drag-line type of cleaner. This type of apparatus is effective but is inclined to cut tracks in deposits where flows are small. The water-driven turbine type will do its work well, but the writer does not believe that this latter type of equipment is equal to the revolving spring-steel rod utilizing different kinds of cleaning or cutting heads, and the rubber cups for removing sand or other deposits when backed by a head of sewage.

Flexible sewer rods and machines were found to be valuable cleaners at Boston (*American City*, August, 1942). At Los Angeles, Brown states that nearly one and one-half million feet of sewer lines are cleaned each year with three machines, and the cost of upkeep and personnel was 3½ cents per foot of sewer pipe cleaned. Mr. Brown states that each machine may be set up at 10 to 20 locations a day and can clean from 1500 to 2500 ft. of sewer line daily (*Water and Sewage Works*, p. 249, 1947).

Catch basins at Milwaukee are cleaned once each year. This practice varies throughout the country. In some places they are cleaned as often as once every 3 months, while in other instances the period of cleaning is extended to about once in 3 years, as in Boston. The eductor type of catch basin cleaning apparatus as mentioned for Milwaukee is most effective, and reduces the unit cost for the removal of grit and other foreign material.

In most municipalities, where the water works is owned by the city, there is no problem in securing water for flushing sewers, but where a private company owns the water works, the problem differs materially. Again citing the case of Lower Merion Township, it is cheaper to use creek water for flushing than to purchase water from the private utility. The township, which has an area of 24 sq. mi., has a 700-gal. tank mounted upon a 2½-ton truck, and water is pumped to this tank from a series of creeks or taken from one of the twelve fire hydrants permitted to be used. The tank is equipped with a quick-opening valve, and the contents are discharged rapidly to a manhole for flushing.



CONTENTS OF CONICAL PILES*

Frequently it becomes desirable or necessary to estimate yardage in a pile of dirt, sand, stone, gravel, coal, etc.

Without any figuring whatever the accompanying chart quickly gives the number of cubic yards in any conical pile.

For example, how many cubic yards in a conical pile whose based diameter is 100 ft. and whose height is 10 ft.?

The dotted line drawn across the chart shows how it is done. Run the line through the 100 ft. diameter, column A, and the 10 ft. height, Column C, and the intersection with column B gives the answer as a little less than 1000 cubic yards.

The range of the chart takes care of all diameters from 5 to 500 ft. and all heights from 2 to 200 ft. However, in the event that diameters or heights should be greater or less the same chart is still applicable. Thus if the diameter should be 1000 ft. instead of 100 ft. and if the height should be 100 ft. instead of 10 ft., the same dotted line would solve the problem excepting that the answer would be 1,000,000 cubic yards instead of 1000 cubic yards. In that case the rule is this: For every cipher added to column A, add two ciphers to the answer in column B, and for every cipher added to column C, add one cipher to the answer in column B. This means that when the problem is 1000 ft. diameter and 100 ft. height, three ciphers must be added to the result in column B.

*Contributed by W. F. Schaphorst, M.E.

PRIMARY TREATMENT

THE GENERALLY accepted definition of primary treatment is the removal of discrete solid particles from sewage by physical or mechanical means. There are three processes involved: Sedimentation, screening and flotation and the first of these is the most important.

Sedimentation generally takes place in two stages, utilizing a difference in specific gravity to separate different kinds of particles. The first stage is grit removal where heavy inert matter (sand, cinders etc.) is removed, the second stage removes the lighter organic settleable solids. Both stages depend on natural gravitational forces and the maintenance of velocity of flow at some definite rate. This rate must allow the particles to subside or settle rather than keeping them in suspension due to counter gravitational forces created by the relatively rapid forward motion of the liquid and its attendant swirls and mixing characteristics. High velocities will pick up relatively large and heavy particles as well as light and small particles.

Flotation involves the use of the buoyant effect on particles lighter than water. In rapidly flowing liquid these particles tend to become mixed throughout the liquid. When the velocity of flow is reduced these particles, including greases, oils, matches, etc. rise to the surface where they can be removed.

Screening involves the passage of a liquid through some physical device which contains openings of definite size which will allow passage of small particles but will catch large objects.

Grit Removal

All sewage contains grit; even where storm water is completely separated from domestic sewage. It is the function of the grit chamber to remove inert matter particularly sand, cinders, etc. If the velocity of flow of sewage is reduced to less than 1.0 ft per sec but more than 0.7 ft per sec then particles with a specific gravity of 2.6 and a size of 0.2 mm in diameter will be removed. Smaller particles will not settle.

Grit chambers are usually designed to allow from 20 to 60 seconds detention time; the shorter time being used in small plants. Provisions must be made for removing the settled grit. In smaller and older plants, duplicate chambers are used so one can be taken out of service for hand cleaning. In newer and larger plants, grit chambers are designed with mechanical equipment (flights, scrapers and buckets) for the continuous removal of the settled grit particles.

In most sewage plants, some organic matter, particularly garbage particles, earth worms, and some sewage particles will settle out with the grit. This organic matter is putrescible and might cause odors if the grit is used for fill. To remove this organic matter the grit is washed in special mechanical washers which return the organic matter to the sewage and discharge a clean grit.

The amount of grit removed depends on the particular plant and characteristics of the sewage. The volume of grit may be less than 1 cu ft per mil gal or as high as 4.5 cu ft per mil gal, particularly where a combined sewer system exists.

Screening

To protect pumps and to remove large suspended and floating solids screens are used. These are usually constructed of inclined bars spaced from ½ to 5 in. apart. Sewage passes through these bar screens at velocities of 2 to 3 ft per sec. In small plants, screens are cleaned by hand raking, but in large plants mechanical rakes are used. Basket screens have also been used as have cages for trash racks. Mechanical rakes are usually operated on a time cycle or loss of head basis.

The amount of screenings, composed of rags, paper, parts of clothing and other discarded personal effects varies with the community. Screening quantities run from 0.7 to 4.3 cu ft per mil gal. This material is wet, odorous, putrescible and generally objectionable.

Screenings removed from sewage may be buried, burned or mechanically ground and returned to the sewage, particularly where mechnical raking of the screens is practiced. Another practice is that of grinding (comminuting) the screenings beneath the surface of the flowing sewage by movable shredder blades which rotate or oscillate between the openings of a ¼ in. slotted drum or flat screen.

Few installations exist where fine screens with relatively small openings (1/32 to 3/32 in.). The quantity of solids removed on these screens amounts to 10 to 20 per cent of the suspended solids. These screens may be flat discs rotating on an inclined axis, a rotating drum, or an endless belt. The Reinsch-Wurl type is the most widely known—all types must be continually cleaned to maintain efficiency and prevent clogging.

Sedimentation

Sedimentation of sewage solids is the main function of primary treatment, but as solids are removed so too is a portion of the B.O.D. Sedimentation may take place in Imhoff tanks, or in settling tanks equipped with mechanical sludge removers.

The Imhoff tank is a two story tank, in the upper portion of which, settling takes place, while digestion of the settled solids proceeds in the lower compartment, separated by baffles from the settling compartment.

Plain settling tanks with mechanical sludge removers are termed clarifiers. They are usually fairly shallow tanks, circular, square or rectangular in which mechanical flights or scrapers push the settled sludge to some one point from which it can be transferred to digestion tanks.

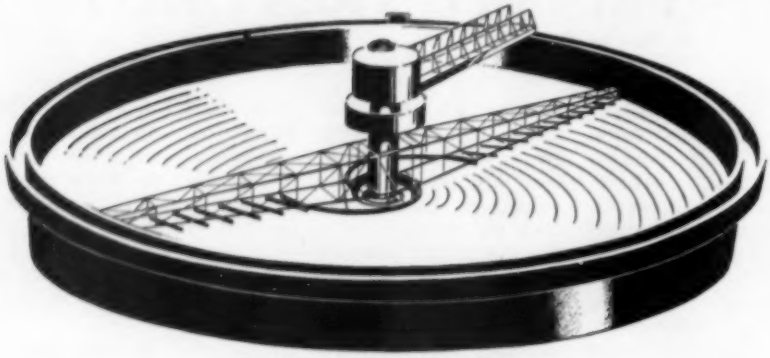
In well designed clarifiers, 55 to 60 per cent of the suspended solids (or 85 to 90 per cent of the settleable solids) will be removed. At the same time approximately 30 to 35 per cent of the B.O.D. will be removed. In order to improve these removals by 15 to 20 per cent, certain aids to primary treatment may be practiced. These aids include mechanical flocculation and chemical precipitation and effluent filtration on magnetite filters.

Flotation

Some of the removals obtained in settling tanks include suspended matter with a specific gravity less than one. This matter will rise to the surface of settling tanks and can be skimmed off and removed for disposal. An aid to the flotation process air may be introduced, in fine bubbles, into the sewage to aid in floating nonsettleable solids.

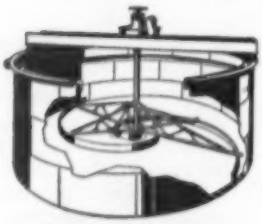
The material which settles out becomes raw sludge, that which floats is skimmings. The disposal of these is a subject in itself.

HARDINGE SANITATION EQUIPMENT



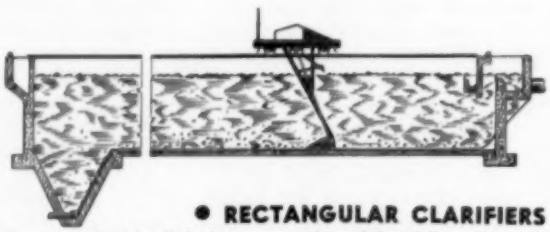
• CIRCULAR CLARIFIERS

Hardinge Circular Clarifiers are available in sizes up to 200' diameter, either center-column or beam supported for steel, concrete, wood or tile tanks. Sludge scrapers remove settled solids rapidly through central underflow discharge. Bulletin 35-D-15.



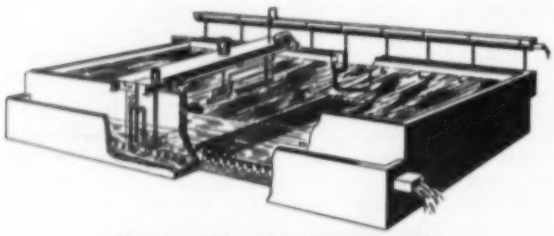
• THICKENERS

For removal of fine suspended solids from supply water, waste water and sewage. "Auto-Raise" mechanism prevents scraper breakage. Bulletin AH-442-15.



• RECTANGULAR CLARIFIERS

Especially suited for limited spaces or where sludge delivery is desired at one end of the tank. A traveling scraper and skimmer carriage removes settled solids from the tank bottom and scum from the top. Bulletin 35-D-15.



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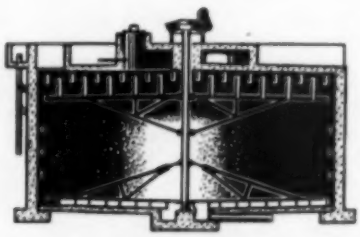
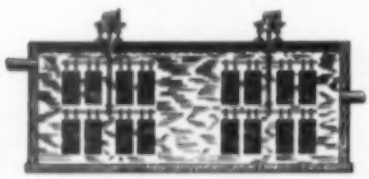


• DIGESTERS

Sludge scrapers and scum breaker arms prevent scum accumulation, insure uniform gas production. Emit a dense digested sludge. Bulletin 35-D-15.



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Primary Units in Sewage Treatment Works*

Maintenance and Operation

by FRANK H. MILLER

Chief Engr., Hampton Roads, Va., Sanitation District Comm.

BY DEFINITION, maintenance is the holding or keeping in a state of efficiency and operation is the performance of work or acts to produce an effect. For all practicable purposes sewage treatment is an industry in which raw material is converted by sound engineering, chemical, and biological practice to products more nearly meeting the required needs. This industry must be operated, however, with little or no control over the quantity or quality of its raw material, but must still produce results or "consumer goods" which are both uniform and acceptable. The proficiency with which the facilities available can be maintained and operated will usually be the index of success in converting the unwanted raw material to one which will be acceptable to at least the majority of the industry's "market."

Plant and equipment design are so significant to the ability to maintain efficiency and secure required results that brief comment is warranted on some of these factors that it is felt have been important in connection with the primary treatment facilities in the Hampton Roads Sanitation District.

The District has now had in operation for approximately five years three primary treatment plants, the primary units of which are substantially the same and consist of four-tank settling basins operating in parallel, each of which is divided into two sections. Each section is equipped with separate chain-and-flight equipment and scum removal equipment; each tank or each two sections is equipped with cross collectors of either the chain-and-flight or helicoid type. The plants have a theoretical settling capacity adequate for approximately 10 m.g.d. at the Army Base in Norfolk, 22 m.g.d. at Lamberts Point in Norfolk, and 12 m.g.d. at the Boat Harbor plant in Newport News. Anticipating the question that practices in these plants may be different, due to size, from those of a smaller or a larger plant, it is doubted that there is any material difference in the basic maintenance and operation requirements for producing good results merely because of variation in size or number of units used.

Access to Channels

Design at one of the plants included an almost completely concrete slab covered rectangular influent channel supplying the four basins. The influent ports from this channel to the basins are equipped with shear gates, but the top of the ports is approximately 1.5 ft. below the normal flow line of the channel. It is, therefore, not accessible for either observation or cleaning. Scum tends to accumulate, particularly near the ends of the channel, to some extent restricting flow to the farthest removed basins. Experience prompts the caution that every influent channel be kept uncovered to the maximum extent consistent with good design and that under no conditions should the ports between this distribution channel and the basins restrict the free transmission of scum or other floating material between the two. That is, the flow line, like the floor line, should be entirely clear of ledges, baffles, or other obstructions. Experience also indicates that full-depth influent gates, preferably of aluminum with aluminum guides, more than justify their added cost in reduced cost of maintenance and operation. Gates of wood with iron strapping also are to be avoided wherever practicable.

Settling Basins

Unequal distribution between multiple settling basins served by a common influent channel can badly unbalance the loading to the respective basins. The most effective distribution seems to result where the flow is toward a wall constructed perpendicular to the flow direction, with distribution laterally from this point.

Access to all flumes and channels and to the side walls of sedimentation basins, and elimination of overhang on these operating walls, greatly simplifies normal maintenance and operation. There are, of course, limits to which this can be accomplished. But by judicious use of gratings and minor alterations in design, operating problems will be simplified by anything done toward this objective.

Sludge Collection Equipment

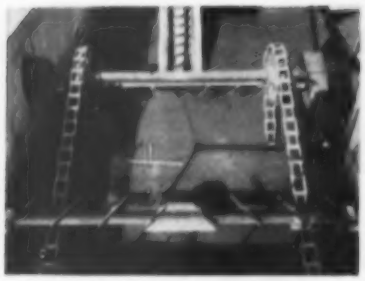
As regards mechanical sludge collection and cross collection equipment, there is a wide divergence of views. It is not desirable, however, to use any flight of greater than 6-in. depth. Also, helicoid rather than chain-and-flight-type cross collectors reduce maintenance and operation problems, split-type main drive sprockets are preferable to the solid type, and a square key and keyway-type of clutch on the drive mechanism is preferable to the sawtooth type. Several manufacturers either will not or are reluctant to furnish flights deeper than 6 in. on the basis that a 6-in. flight is sufficient to handle any sludge loading within the tank, and no good is obtained from any additional depth. Deeper flights ride on their bottom leading edges and do not pass smoothly down the tank, but tend to advance in jerks or hops.

Objections to chain-and-flight-type cross collectors at the influent end of the basin are (a) there are many more moving parts, which increases the maintenance, and (b) usually they do not permit the use of a type of basin influent baffle that will prevent the flow from being diverted downward into the hopper, where it is likely to cause scouring of the accumulated sludge. Personal observation further indicates that the flights themselves result in greater agitation of the sludge than do the helicoid-type collectors.

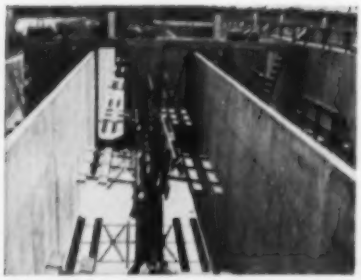
Split Sprockets

Anyone who has had to replace a solid or one-piece drive shaft sprocket where the sprocket cannot be readily slipped off the end of a short shaft will recognize the advantage of the split-and-bolted type of sprocket. In the Hampton Roads plants, time of installation is reduced by use of the split type from an average of possibly 6 to 8 man-hours to less than one-fourth as long. The cost differential for the most common sprockets is only that between approximately $19 and $27. As a matter of information, considerable difficulty was experienced in finding a useable split-type sprocket, but they are now available for use on most makes of equipment. This does not mean that this type sprocket

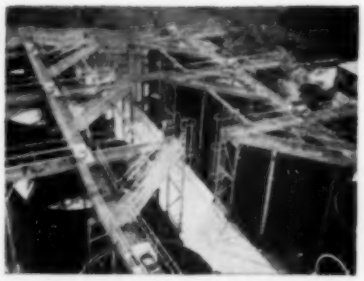
*Reprinted from *Sewage and Industrial Wastes*, Vol. 26, p. 96, by permission of FSIWA.



Grit collectors and washers effectively remove grit and separate putrescible organic matter before removing.



Straightline mixers for rectangular tanks, horizontal flow. Degree of mixing can be varied to produce maximum size floc.



Flash mixers rapidly and thoroughly mix chemicals with water, sewage, and industrial liquids. Propeller shaft has no underwater bearings.

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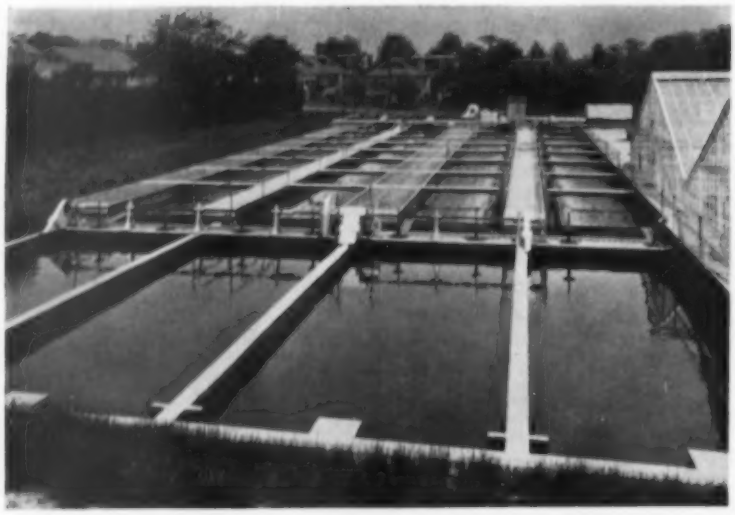

15 YEARS' SERVICE — Link-Belt chain installed at this Collingswood, N. J. activated sludge plant gave 15 years of continuous, 24 hours per day service *without replacement!* Straightline collectors in primary tanks have been in service for 24 years without replacement. Machinery reflection indicates clearness of effluent.

LONG life decides the eventual economy of sanitary waste treatment equipment. And after years of operation, Link-Belt systems in cities both large and small continue to provide highly effective water purification and sewage treatment service . . . with negligible maintenance expense.

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Link-Belt offers you a broad line of top-quality equipment . . . plus engineering proficiency acquired in over 34 years' experience. Our specialists will be glad to work with your own engineers, chemists and consultants to bring you the finest in modern treatment methods. Call your nearest Link-Belt office for full information and catalogs on the Link-Belt products shown here.

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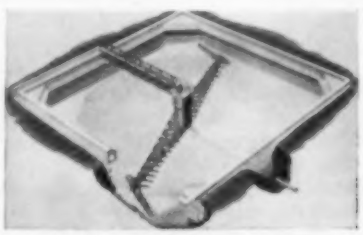
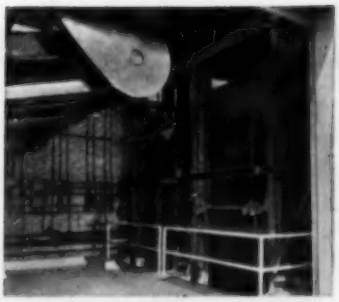
Straightline collectors for rectangular settling tanks. Peak-cap bearings, pivoted flights and Straightline action assure top efficiency.



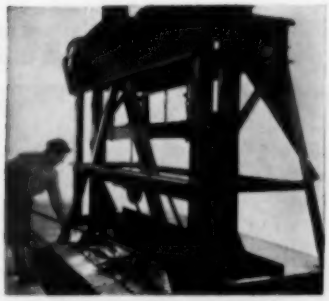
Circuline collectors for square or round tanks for quick, positive sludge and scum removal in shortest time without septicity.

Bio-filtration systems utilize high-rate shallow filters and recirculation of effluent from filter to primary settling tanks and recirculation from final tank to filter. Single- or two-stage.

Thru-clean bar screens remove large floating particles from large volumes of water, protect other equipment.

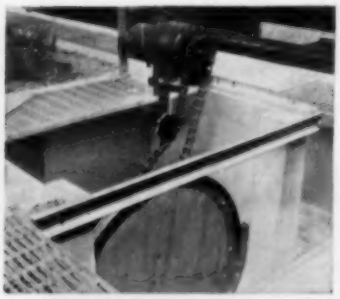


Straightline bar screens can't jam, assure constant, automatic screenings removal under extreme conditions.

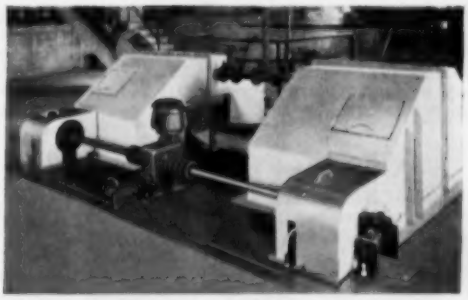


Trash screens provide thorough removal of large debris from water and power plant intakes.

Tritor screens remove both grit and screenings with one mechanism. Recommended for small sewage plants.

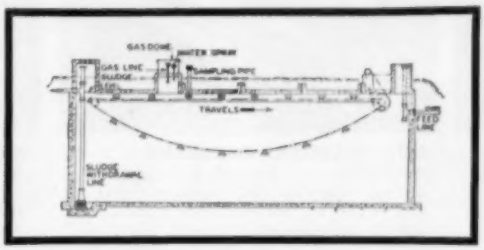


Revolving disc screens offer economy and minimum loss of head.



Rotary drum screens remove fine solids from surface intakes, settling tank effluents and industrial wastes.

Liquid Screens are widely used for removing fine solids from liquids. Several sizes, with fine cloth.



Scum breakers are installed in either round or rectangular digestion tanks to break up the floating scum as well as paddle down and submerge it. Mats of scum are prevented, and no breaking down by hand is required.

Belt Conveyors—one of various types of conveyors available for handling bulk or packaged chemicals.

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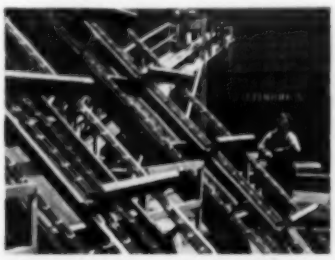

Chains for any conveying or power transmission need can be found in Link-Belt's complete line.

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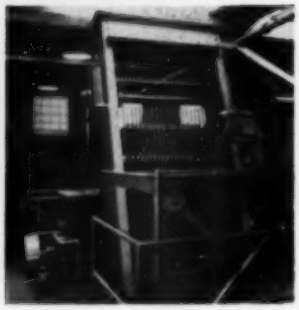

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RAPID MIXERS . . . for mixing coagulants with raw water ahead of flocculation basins. Special turbine designed to produce horizontal and vertical mixing for proper blend.

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can always be purchased from the manufacturer of the equipment. If the required sprocket is carefully specified, however, there is no reason to go to the original manufacturer for replacement. This has the additional advantage of permitting competitive purchase and applies to a large majority of the other chain-and-flight equipment, as well as to the sprockets.

Clutches and Drives

Objection to sawtooth-type couplings on drive equipment is based largely on the high breakage rate experienced. The key-and-keyway type eliminated this difficulty to a great extent. Usually it is a slightly cheaper type of clutch and operation with it seems equally as satisfactory.

Another source of considerable trouble resulted from the direct coupling of a drive motor to the gearbox mechanism. For some reason, alignments were most difficult to maintain and failure of alignment resulted in breakage, motor troubles, and frequent repairs. In lieu of the original equipment several V-belt drive connections have been installed between motor and box. These have completely solved the problem.

Another design characteristic in one of the plants, which also has been seen in several others, is the use of a full-length wood partition between sections where a basin is separated into two parallel sections. The purpose, of course, is to prevent short circuiting or crossover of flow between the two sections. Two of the Hampton Roads plants do not have such a longitudinal baffle, yet no difference is observable between the plants in the efficiency of function. The basins are more easily operated and certainly more easily maintained if the baffles are not used.

Other Comments

Other comments regarding particular points of design that it is felt have affected maintenance and operation concern the provision of sludge wells and suitable telescoping valves in the well and the question of using relatively new and untried designs or types of equipment.

At the one Hampton Roads plant not equipped with a sludge well and telescoping valves, so that direct pumping from each basin is required, it is a continuous problem of training, retraining, and threatening to keep operators from either inadequately pumping sludge or, equally as bad, from over-pumping to the digesters. In spite of all the good theory as to control by taking regular samples from the sludge pump, experience indicates that in practice this method of sludge removal too frequently is the cause of either over- or under-pumping the basins.

The word of caution as to the untried stems from relatively few such conditions existing in the local plants. Nevertheless, as with practically every plant, some do exist. Generally it is preferable to have had the "gimmicks" given a thorough trial by somebody else and to use only proven designs.

Maintenance Standard

Probably the most difficult job faced by anyone is to secure and keep a continuously adequate maintenance standard. This applies equally to primary units as to some of the more complex equipment or functions. The difficulties at Hampton Roads were normal and to be expected, in that within a period of one year the Commission placed in operation its 3 treatment plants, some 30 pumping stations, and some 65 mi. of major interceptor sewers. There are in the system, just as one example, approximately 325 electric motors, totaling more than 2,400 hp.; also, more than 2.5 mi. of pintle chain is used, mostly in primary treatment units.

The Commission had no existing organization from which it could expand. The present operating personnel, now totaling about 70 employees, has been recruited, trained, and held responsible for functions in which they had absolutely no experience, with one or two exceptions, just five years ago. Also, there has been a constant heavy personnel turnover due to the critical defense status of the Hampton Roads area and the fact that competitive employers had a virtually complete disregard for pay scales if they needed a man.

The treatment plants are operated basically on a system that places one man in responsible charge of routine maintenance, including repairs and replacements of a minor nature, and lubrication. Major replacement or repair is the responsibility of a maintenance section, which is available for work in or outside of the treatment plants.

Maintenance Records

The employee responsible for routine maintenance in the plant is required to keep complete records on each piece of equipment and to accomplish his functions on a planned schedule, compliance being noted each time the function is performed. A system of 5-in. by 8-in. maintenance cards is used on primary treatment as well as other units.

The record system is generally modeled after the army system (1), although the basic system has been simplified in many ways. Two cards are kept on each unit of mechanical equipment. One is an equipment record; the other is an inspection and service record. The equipment record card has on the front complete data as to that unit. (For example, on a motor the serial number, style, frame, class, and any other available characteristics or nomenclature is noted.)

Such a card is made up for each motor, gearbox, chain assembly, etc. It is also valuable as a permanent record for needed replacements and helps greatly to assure that orders will be placed in proper form to avoid confusion on the part of the supplier as to what is needed. On the bottom and back of the card there is a space for entry of non-routine types of maintenance or checks.

For example, all motors are resistance tested with a "megger" at regular intervals by the electrician, who at the same time takes ampere readings and observes the condition of the motor. These data are noted. If winding resistance varies, indicating insulation failure, the motor is dried out or other checks are made to whatever extent is indicated. Likewise, an increase in ampere reading indicates excessive loading or similar difficulty and the cause is sought out and corrected before serious trouble occurs. At the time of the check a notation is made of the work done, including with it the date and the initials of the person in charge of the work.

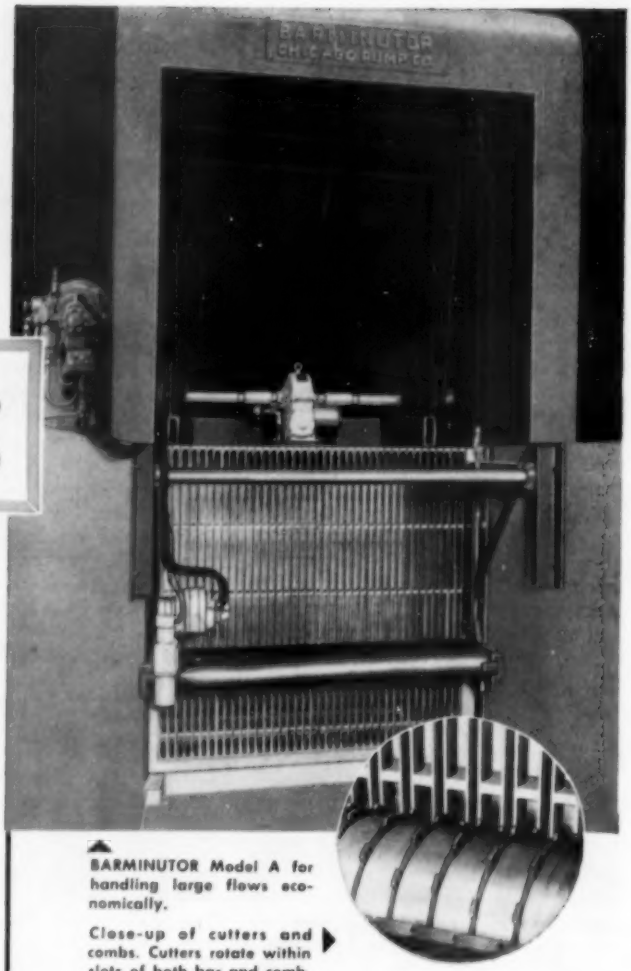
The second card, covering routine inspection and service, includes on the front a summary of maintenance and lubrication requirements. For example, the front of the card might show (a) motor bearings — lub. each 6 months, (b) gearbox — change oil every three months, and (c) check gearbox oil each month. On the back of this card the plant maintenance man enters the work done, either by reference number to the function required on the front of the card, or by description, showing also the date of service and his initials.

The cards are separately classified as a guide to the work that needs to be performed. They furnish a permanent record, both as to maintenance accomplished and as to the maintenance requirements over a period of time, on equipment of various makes and types.

As an adjunct to maintenance of equipment, an extensive effort has been made to secure manufacturer's shop and section drawings of each piece of equipment so that data are available as a guide to the proper dis-

NOW - A Proven Teammate for the COMMINUTOR screening and cutting machine

The BARMINUTOR®
screening and comminuting machine



BARMINUTOR Model A for handling large flows economically.

Close-up of cutters and combs. Cutters rotate within slots of both bar and comb.

Gives Same Clean, Continuous Disposal of Coarse Sewage Matter ...without Removal from Channel

No disposal problems, no unpleasant servicing—the BARMINUTOR screening and comminuting machine cuts all coarse sewage material into small, readily settleable solids — without removal from the channel — eliminates raking, burial, incineration and grinding. The operation is continuous: manual attention is unnecessary except for periodic lubrication, inspection and cutter sharpening. Power requirements are lower than for mechanically raked screens and grinders. Since all cutting is done above the grit line, wear is greatly reduced. Proved economical design of cutting parts provides low cost replacement.

EFFECTIVENESS PROVED

Over 4000 COMMINUTOR screening and cutting machines installed since their development by the Chicago Pump Company 21 years ago stand behind the BARMINUTOR screening and comminuting machine. More than five years of actual operation preceded the installation of the BARMINUTOR screening and comminuting machine at a number of modern treatment plants. At the Indianapolis, Indiana Sewage Plant, a BARMINUTOR screening and comminuting machine was subjected to test loads of screenings up to six times the normal 40 M.G.D. load. Comminution time: 6 minutes. Head loss: not in excess of 6".

IDEAL FOR TREATMENT PLANTS, PUMPING STATIONS, OUT-FALL SEWERS

The BARMINUTOR screening and comminuting machine can be installed in existing influent channels from one to twelve feet wide. No special basin or channel shape is required. Descriptive literature and engineering data is available on request. Write Dept. M.

CHICAGO PUMP COMPANY
Subsidiary of Food Machinery and Chemical Corporation
SEWAGE EQUIPMENT DIVISION
622 DIVERSEY PARKWAY • CHICAGO 14, ILLINOIS

Flash Dryers, Screw-Feeders; Plunger, Horizontal and Vertical Non-Clog, Water Seal Pumping Units, Stampers.

Swing Diffusers, Stationary Diffusers, Mechanical Aerators, Combination Aerator-Clarifiers, Comminutors.

Aer-Degritter and Comminutor installation, Mayfield, Kentucky. Design flow 1.5 M.G.D. Russell, Axon & Associates, Engineers.

AER-DEGRITTER*

Air Controlled Settling Velocities Independent of Flow

The Aer-Degritter* removes grit and sand from sewage through the use of air to effect a controlled velocity of the sewage in the grit tank. The method provides a quiescent zone beneath the air diffusion media to effect a selective deposition of clean grit without organics. There is no need for separate grit washing tanks. Washing and deposition are effected in a single tank.

The principle of air controlled velocities was first demonstrated in sewage treatment plants designed by the office of Charles H. Hurd, Consulting Engineer. The Hurd method, using diffuser plates located behind the hopper, was an improvement over the then practiced means of controlling grit tank velocities. The Aer-Degritter* using diffuser tubes located directly above the hopper is, in turn, an improvement on the Hurd method.

POINTS OF SUPERIORITY OF THE AER-DEGRITTER*

1. Relative location of grit hopper and air diffusers. In the Aer-Degritter* the diffusers are elevated above the tank floor and the grit hopper is directly beneath the air diffusers. This permits greater flexibility of control of tank bottom velocities regardless of volume of sewage flow. It is these bottom velocities that control the deposition of clean grit and fine sand without also depositing organic material. Tests made on grit removed by Aer-Degritters* have consistently shown less than 0.05% putrescibles.

2. The equipment used to introduce air to the sewage. The use of Swing Diffusers and Precision Diffuser Tubes permits easy access to the grit hopper and cleaning of the diffuser media without taking the tank out of service.

*The application of the equipment, as well as the equipment itself is covered by U.S. Patents No. 2,532,457, No. 2,144,385, No. 2,328,655 and No. 2,555,201.

OVER 60 AER-DEGRITTERS IN* OPERATION IN LARGE AND SMALL PLANTS

CHICAGO PUMP COMPANY

Subsidiary of Food Machinery and Chemical Corporation

SEWAGE EQUIPMENT DIVISION

622 DIVERSEY PARKWAY • CHICAGO 14, ILLINOIS

Flush Kleen, Screw-Feeder, Plunger, Horizontal and Vertical Non-Clog Water Seal Pumping Units, Samplers.

Swing Diffusers, Stationary Diffusers, Mechanical Aerators, Combination Aerator-Clarifiers, Comminutors.

Write to Department G for Engineering Data

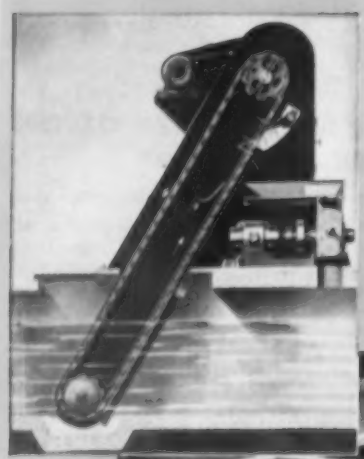
fmc

we treat them all like

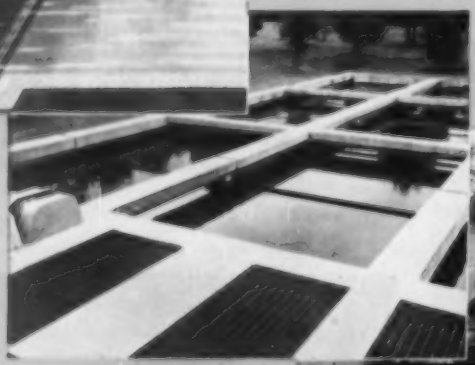
finger prints!

Just as no two sets of finger prints are ever alike, so, too, are all sewage and waste treatment problems *different.* Velocities, head loss, capacities, site conditions, tank or chamber hydraulic conditions, and many other factors vary from plant to plant. That is why we at Chain Belt have no standard answer to a treatment problem. We study each application carefully, and from our broad background of experience recommend the type and size of equipment you need for most efficient, economical results. From the broad range of Chain Belt Sewage and Waste Treatment Equipment, we select the exact units that can be best adapted to your particular conditions.

So, don't just specify equipment. Ask your nearest Rex Sales Engineer to work with you to assure the results you want, or write direct to Chain Belt Company, 4610 W. Greenfield Ave., Milwaukee 1, Wis.



Rex Mechanical Cleaned Bar Screens and Triturators



Rex Vertl-Flo® Clarifiers

Rex Conveyor Sludge Collectors

Rex Grit Collectors

CHAIN BELT COMPANY

District Sales Offices in all principal cities

assembly or reassembly of equipment and as a further check on the exact type or number of parts for ordering purposes. During the past two years operation has been taken over of a few installations including relatively old equipment where this information is not available. Inability to obtain the information in several instances has resulted in delay of work on the equipment and in obtaining incorrect replacement parts when they were needed. As a result of this experience, it is deemed most essential to accumulate this information while equipment is relatively new and standard and the information regarding it is available from the manufacturer. It might be added that the manufacturers of equipment in the District's plants, and this includes possibly 200 or more, have been most cooperative in furnishing the information. In most instances they were more than glad to do so, as it permits them to render prompter and more efficient service.

Outage Tags

Despite moderate criticism of the "gimmicks" that designers and manufacturers have given the plants the doubtful privilege of trying out, there probably are as many of "home" conception as are likely to be found anywhere, including automatic proportioning samplers, automatic chain oilers, and several others.

One of the most valuable of these of a simpler type is a bright yellow shipping tag, for which a rubber stamp was made with letters about ¾-in. high saying "DANGER—DO NOT OPERATE." There is sufficient space on the card for notes as to the reason and who said so. This card has a string attached and whenever any piece of equipment is found—by the electrician, maintenance foreman, or anyone else—to be in a dangerous condition or otherwise unsuitable for operation until some change or repair is made, the tag is hung conspicuously on the equipment or on its controls.

This simple bright yellow tag has made a material difference in the degree of trouble encountered and has been responsible for saving several pieces of equipment that might otherwise have suffered major damage. Particularly, as at Hampton Roads, where a relatively large number of people have some duty to perform in connection with separated units of the operations, there was a strong tendency to let the equipment go when first signs of trouble were noted, or not to pass on the word to others who would be interested. Use of the card seems to encourage taking equipment out of operation until it is adequately checked out for use.

Personnel Problems

Routine operation of primary treatment units is more closely related to personnel and the usual personnel factors than to any other single influence. If it were possible to keep the same group of operators in the plants for an average of at least four or five years, the costs, treatment efficiency, and maintenance would reflect a degree of improvement unlikely to be equalled by any other single factor. With the two-fold objective of, most important, just being sure of getting help and, second, of trying to keep present help for longer average periods, the plant operators' pay scales have been increased between 1949 and 1953 from a range of $2,412 to $2,772 to a present range of $3,168 to $3,744 per year. Even with the current scale, turnover during the six-month period ending in May, 1953, in operators alone averaged 15 per cent. However, it is materially reduced from experience of early 1952, and the present improved pay scales offer more hope.

Basic Operation Factors

Basically, operation of primary treatment units involves only three principle functions: (a) prompt and effective removal of settled sludge, (b) removal of odor-producing scums from the tank, and (c) performance of necessary housecleaning and minor maintenance functions in a manner which will prevent unsightly conditions or fouling of the treatment units or the equipment integral to these units.

It is impossible to state the exact procedure that should be followed in the removal of sludge in a way that will apply to plants of different location, different loading, or slightly varied design. It may be interesting to review the Commission's pattern of operation, which is probably reasonably typical for the larger plants.

The plants are operated by three shifts of personnel. Each primary sedimentation unit is operated on a basis of five cycles daily, with one being scheduled on the night shift (midnight to 8:00 A.M.) and two each on the day shifts (8:00 A.M. to 4:00 P.M. and 4:00 P.M. to midnight. On each cycle the following procedure is followed:

The main flight mechanism is operated long enough to carry the flights once the full length of the basin; that is, if a flight is at the bottom effluent end of the basin the equipment is run long enough to bring this flight to the sludge hopper at the influent end. This requires approximately 1 hr. The cross collectors are started after the main flights are stopped, and remain in operation until sludge withdrawal is complete. This cannot be followed as an exact pattern where shallow sludge hoppers are used, as in the Boat Harbor plant, which is equipped with flight-type cross collectors. Here the storage is inadequate in the hopper and the cross collectors must be operated for a few minutes before the main flights are stopped, most of the sludge being pumped while both the main flights and the cross collectors are in operation. Sludge is withdrawn at as even a rate as is practicable to the sludge well, where one is available, or by direct pumpage at the minimum practicable rate where the well and telescoping valve is not available. Time of withdrawal using telescoping valves and sludge wells is variable from as little as 3 hr. per day total up to 16 or more hours; where sludge is pumped direct, from a minimum of about 6 to 11 or more hours per day.

The schedule of these operations can readily be adopted to local operating conditions, but these conditions must be studied, a schedule worked out in keeping with them, and operators must be alert to variations from the norm if one is to avoid sludge rising in the primary tanks due to inadequate removal, excessive wear on operating equipment due to over use by unnecessary operation, overloading of the digester by pumping of too much thin sludge or plain sewage, or breakage of flights and other equipment by excessive sludge accumulations.

Adequate operation necessarily demands adequate operating records, including records of primary unit operation, which should show the amount of sludge pumped, any discrepancies from normal operation, and any special functions of housekeeping, parts replacement, etc., performed. Accumulation of such records is the only means by which an economical and effective pattern of operation can be established over a period of time.

Operational duties also include sampling in accordance with the established schedule and interpretation of observations, such as condition of sludge being withdrawn in a proper manner. As with most sewage treatment personnel, the plant operator's ability to understand the fundamentals of what he is doing and to reason logically as to the effect which his procedures will have on the over-all operation is the most important single factor in the results to be obtained. Of our three shifts each day, two are covered in each of the three Hampton Roads plants by a single operator who is on

duty with one laborer-helper. It is difficult to exercise supervision during these shifts and the only substitute for such supervision is the proper training of the operator and his full acceptance of the responsibility for carrying out his duties effectively.

As a matter of scheduling, most of the minor housekeeping functions, such as minor painting, grass mowing, and other duties of this type, are logged by the chief operator to be performed by the shift operator or his helper on either the evening or night shifts. In this way practically full utilization of the operator's time on duty is secured. Operational duties of a less routine nature are usually performed by the day operator and helper, or by the maintenance man or the chief operator, both of whom are normally scheduled for the day shift.

In conclusion, the structures and equipment for sewage treatment, exclusive of transmission facilities, represents at Hampton Roads an investment of approximately $30 per service unit connected to the system. This is a relatively low figure. Operating costs for both maintenance and operation of the three treatment plans is approximately $2.85 per unit served per year. Annual operating and maintenance cost is approximately 9 per cent of the slightly more than $3,000,000 capital cost initially spent on treatment facilities, at present being approximately $20 per million gallons treated. By any yardstick, the money spent on operation and maintenance is a small share of the capital investment in facilities which have been made available.

The maintenance and operation secured largely govern the effective life of the structures and equipment for which the capital was expended, and the degree to which it performs the functions for which it was intended. It is, therefore, imperative that the necessary money be made available as well as that it be spent wisely, in order to safeguard both the useful life and the effective use of the facilities being held in trust.

Reference

1. U. S. War Dept., "Inspections and Preventive Maintenance Services—Sewage Treatment Plants and Sewer Systems at Fixed Installations." War Dept. Tech. Man. 5-666, U. S. Govt. Printing Off., Washington, D. C. (Sept., 1945).

R&D

EXPANSION CHART*

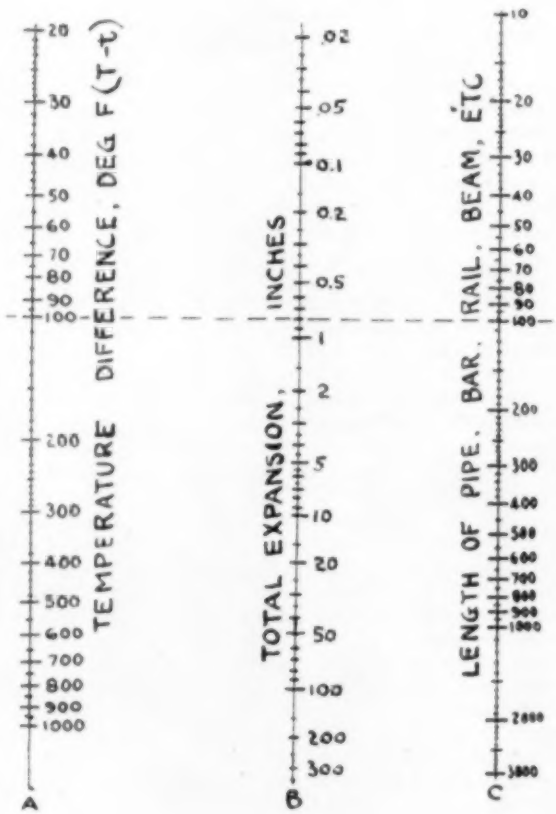
This chart is useful for determining the expansion in piping, rods, tubes, beams, shafts, columns, struts, etc., for any ordinary temperature difference. It makes "longhand figuring" unnecessary. Simply lay a straight-edge across the chart once or stretch a fine black thread across, as indicated by the dotted line, and the problem is solved.

Example: If a certain pipe line 100 ft. long is subjected to a temperature variation of 100 deg. F., what will be the total expansion in inches?

Simply connect the 100 deg. *temperature difference*, column A, with the 100 ft. length, column C. The intersection with column B gives the answer as 0.8 in. That is all there is to it.

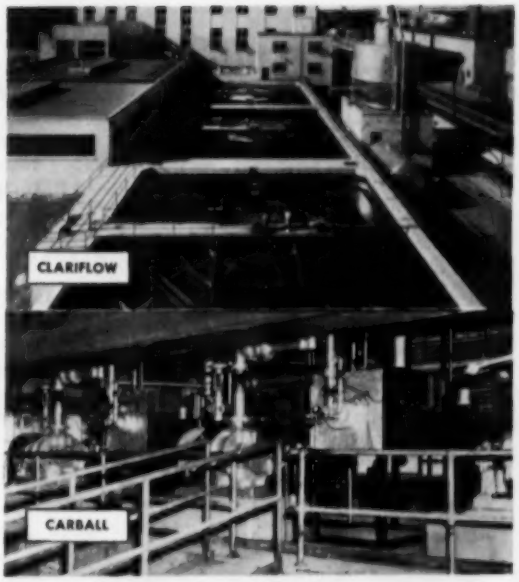
The chart can also be used for determining the allowable temperature difference where a definite amount of space is available for expansion and contraction. Thus if the length of the pipe is 100 ft. and the allowable expansion is 0.8 in. the same line would show that a temperature difference of 100 deg F. would be the limiting amount.

*Contributed by W. F. Schaphorst, M.E., Newark, N.J.



WALKER PROCESS

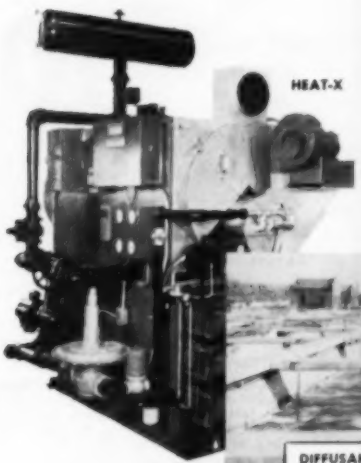
Equipment for All Water, Sewage and Waste Treatment Processes



WATER TREATMENT

CLARIFLOW—a short retention, vertical rise clarification unit combining chemical homogenizing, flocculation, clarification and positive sludge removal for softening and turbidity, color and algea removal. Designed for rectangular, square or circular basins.

CARBALL—produces a clean, tasteless CO_2 gas for carbonation. Burns either oil or gas at high temperature and pressure resulting in dry, clean CO_2 suitable for direct diffusion into carbonation chamber.



SEWAGE AND WASTE TREATMENT

HEAT-X—a complete digester sludge heating unit including heat exchanger, boiler, burner and all controls. Burns sewage gas, oil and natural gas, singly or in combination. Absolute and independent control over each function of sludge heating.

DIFFUSAIR—aeration equipment for mixing and oxygenation of tank liquors. Self cleaning air Spargers do not clog or cause back pressure build-up on blowers. High rate tank turn-over and oxygenation results in greater plant capacity.

INDUSTRIAL LIQUIDS

INDUSTRIAL THICKENER—adapts the CLARIFLOW principle to blast furnace flue dust thickening, oil separation, paper stock reclamation and other applications. Permits reuse of process water and reclamation of valuable waste on many industrial installations.

COLLECTORS—for sludge removal in rectangular, square or circular sedimentation basins. Wide range of capacities and sizes to meet all water, sewage and industrial treatment requirements. Designed to suit the most exacting specifications.

WALKER PROCESS EQUIPMENT INC. · Aurora, Illinois

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"Modern Processes and Equipment for Sewage and Industrial Waste Treatment"

PROCESS . . . AND EQUIPMENT . . . FOR SEWAGE AND INDUSTRIAL WASTE

ACTIVATED SLUDGE TREATMENT

BIO-ACTIVATION PROCESS—a patented process combining and utilizing the best qualities of trickling filters and activated sludge in two stages and in such a manner that each stage operates under optimum conditions and at maximum efficiency. Primary treatment is followed by high capacity filters and short period intermediate sedimentation. Here, initial high removals of BOD are obtained before sewage is passed to aeration tanks where activated sludge is developed. Because of the intermediate filter treatment which considerably reduces the strength of the primary effluent, the liquor can be readily handled by the activated sludge process without the usual upsets caused by exceptional conditions and shock loads.

Send for Bulletin 259-B

A Typical Bio-Activation Plant

MECHANICAL AERATION—Consists of a circulating pump with down-draft tube and hydraucone assembly. As liquor passes through the pump, fine bubbles of air are drawn in and intimately mixed with the sewage. This mixture is ejected at high velocity across the tank floor. Consequently, entrained air is distributed uniformly across the tank, and fine air bubbles, rising slowly to the surface, supply sufficient oxygen to maintain the activated sludge process. For large installations, "AMERICAN" Aerators are installed in single, large tanks without dividing walls because the pattern of recirculation sets up hydraulic baffles between the units, thereby eliminating any possibility of short circuits.

Send for Bulletin 265-A

JET AERATION—Injects an intimate mixture of liquor and finely divided air into the aeration tank. No other method of aeration produces the unusually high rate of oxygen absorption at remarkably low cost. Additional aeration economically provided for existing plants. Present diffuser plate or tube installations easily replaced.

Send for Bulletin 265-A

ROTARY DISTRIBUTORS—Reaction and Positive Drive Types. The Reaction type is manufactured with 2, 3, 4, or 6 arms. In general, the 3 arm distributor has the advantage of minimum wind effect, low starting inertia, and perfect balance. The Positive Drive type is rotated continuously independent of the sewage flow, by a motorized gear reduction unit. It is used under conditions of low available head and wide variations in flow. "AMERICAN" Distributors are equipped with a patented dual oil seal which eliminates troublesome and costly mercury, protects bearing surfaces, and will withstand at least 10′ of water pressure.

Send for Technical Supplement "RD"

Send for Technical Supplement TV on Telescoping Sludge Valve

GRIT REMOVAL

AMERICAN CAMP REGULATOR—an adjustable control to maintain velocity of sewage flow thru grit channels at optimum rate, regardless of rate of flow thru plant.

Send for Technical Supplement "CR"

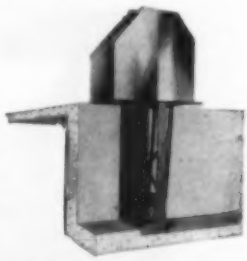
GRIT CONVEYOR—single strand, drag type. Carries grit to hopper for washing and removal.

GRIT HYDROWASH—grit washed free of organic matter by turbulent downflow recirculation of liquor in grit hopper.

GRIT ELEVATOR—tube type, totally enclosed for lifting well-drained grit to desired height. Manual or automatic operation.

Send for Bulletin 249-A

UNIT BAR SCREEN



Mechanically Cleaned Completely Automatic with Exclusive Pivoted Rake Design

SCREENING

MECHANICALLY CLEANED BAR SCREEN AND GRINDER—designed for wide range of channel widths, settings, and arrangements. Grinder attached to sorting tray . . . shredded screenings returned to sewage flow.

Send for Technical Supplement "MS"

PRE-TREATMENT

GREASE FLOTATION UNIT—removes grease and oils, produces simultaneous aeration and agitation, and oxidizes objectionable odors.

Send for Bulletin No. 260-A

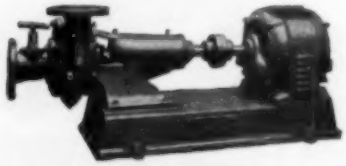


Fig. 5500 Sludge Pump

SLUDGE REMOVAL

POSITIVE FLIGHT CONVEYORS—for rectangular settling tanks.

CIRCULAR CLARIFIERS—for round settling tanks.

SLUDGE AND SEWAGE PUMPS—Fig. 5500 cutting type primary sludge pump. Fig. 5100 enclosed impeller type raw sewage pumps. Fig. 5600 single vane impeller type sewage pumps. Fig. 3400 recirculation pumps. This line of horizontal and vertical pumps ranges in size from 3" to 18" inclusive, in capacity from 40 to 10,000 GPM, and in head from 5′ to 85′.

Send for Bulletins No. 237-A, 250-A, 253-A, 261-A

SECONDARY TREATMENT

Most of the putrescible organic matter in sewage exists in finely divided suspended matter, colloidal matter or dissolved solids. The purpose of secondary sewage treatment is to convert this organic matter into inert mineral substances or stable humus which will no longer create a nuisance.

Secondary sewage treatment is a "wet burning" process. It consists essentially of two steps, first a precipitation or adsorption of the organic matter in sewage on biological surfaces and secondly, a decomposition and oxidation of this organic matter by the biological organisms present in these slimes. The first step has been termed, bioprecipitation and the second, biochemical oxidation.

Historically, the first large scale secondary treatment was broad irrigation. Next came intermittent sand filtration; this was followed by contact beds, then trickling filters and activated sludge. The latter two have been the most important for more than 40 years.

Broad Irrigation

This method consists of applying sewage to relatively level areas of land and allowing the soil to absorb it. In some cases, farming of the land so treated was attempted, to utilize the manurial value of the sewage. Large areas of land are required (approximately an acre to 10,000 gal per day of sewage) and objectionable conditions result with respect to flies and odors. This method of treatment has been eliminated, practically speaking, except for a modified version of the process used in treating canning wastes.

Intermittent Sand Filtration

Intermittent sand filters consist of beds of sand or fine gravel some 2 to 6 ft deep. These beds are equipped with an underdrain system. Sewage is quickly and evenly applied over the surface of the bed, which is allowed to stand from ½ to 3 days, while the liquid drains off and the organic matter is decomposed by biological activity. The number of beds required must be enough to permit the intermittent standing period required. The use of intermittent sand filters will remove practically all of the colloidal and non-settleable solids and will oxidize them but large areas are required and the process is slow. A few of these beds are still in use for sewage treatment, but they are more likely to be found in small installations in Florida for isolated motels, housing developments and for the treatment of industrial wastes and digester decant liquor.

Contact Beds

Contact beds consist of tanks filled with coarse gravel or broken stone ½ to 1½ in. in size. They are filled and emptied from a drain system in the bottom of the beds. The tanks are from 4 to 6 ft deep and provision is made for filling and emptying on some time cycle. Operation is usually on a four cycle basis: Fill with settled sewage; stand full; discharge; and stand empty. The cycle works best with four tanks in rotation. Voids in the stones tend to become clogged, making cleaning necessary. The effluent is usually non-putrescible, but is turbid and high in bacterial content. Operating rates vary from 0.1 to 0.5 mgd with a five foot depth. Few of these beds are in operation today.

Trickling Filters and Activated Sludge

As indicated, these two methods of carrying on secondary treatment are the most important in modern practice. Because of their importance, they will be discussed separately, later in this issue.

Plain Aeration

This treatment consists of prolonged aeration without the return of sludge. In this, it differs from activated sludge treatment. Approximately 70 per cent of the B.O.D. may be removed in 6 to 8 hours aeration. The effluent, however, is turbid. Sludge obtained from this process is generally more dense than activated sludge. The process requires approximately 0.4 to 0.7 cu ft of air per gallon of sewage treated.

Contact Aeration

Another method of secondary treatment is a combination of the contact bed of old and the addition of air. The Hays Process of contact aeration is a two stage method for supplying both surface area and dissolved oxygen in a small area. The first stage consists of a tank with vertical plates on 1¼ to 2½ in centers. (The surface area equals that of a contact bed six times as great in size.) Settled sewage enters at the bottom of the tank and flows upward between the tank plates, with the air introduced over the bottom of the tank through porous diffusers. Sewage is drawn off at the top to a second aerator and thence to a final clarifier.

Another modification of the contact bed is the Lakeside Engineering Co. "Clarifilter", a contact filter and clarifier within a common wall. Air is blown through sewage which passes down through radial "contact sheets", then under a baffle and upward through the central clarifier zone.

Oxidation Ponds

Oxidation Ponds sometimes called lagoons have been used in warm and semi-arid climates, particularly in Texas and southern California. Either raw or settled sewage is added to earth lagoons, 3 or 4 ft deep, with a retention capacity of several weeks. Oxygen for stabilization of organic matter is absorbed from the air and produced by photosynthesis by algae. Loadings of 40 lb of B.O.D. per acre per day are obtainable in warm climates.

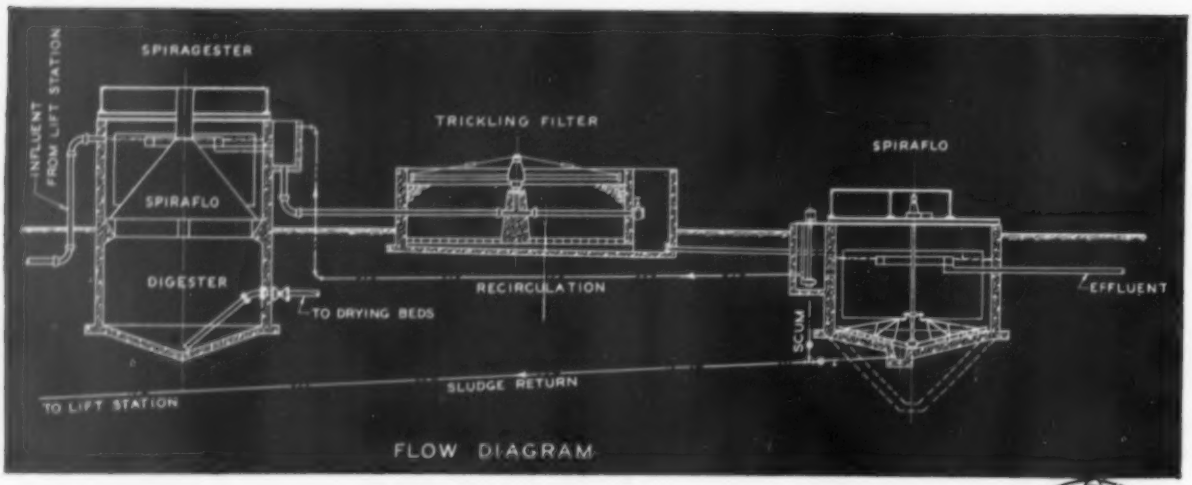
Proprietary Processes

There are several proprietary patented processes in existence. Most of these are variations of the activated sludge process, although there are some variations in trickling filter design and operation. These processes are discussed later in this issue under their respective categories.

Aids to Secondary Treatment

The best aid to secondary treatment is proper control of the process, particularly in the case of activated sludge. Where trickling filters have been overloaded, pre-aeration of 2 to 3 hours has been effective in reducing the load on the filters by 25 to 40 per cent.

"Roughing Filters", course stone single-stage high-rate trickling filters, have effectively reduced overloads and shock loads (20 to 30 per cent) on both activated sludge and trickling filters. The addition of chlorine to sewage before its distribution on trickling filters reduces ponding and Psychoda flies, (DDT, etc is effective for Pyschoda fly control.) Chlorine added to the effluent from activated sludge aerators reduces bulking sludge, apparently by controlling the biological activity, particularly the growth of Sphaerotilus natans, which seem to cause severe bulking conditions. Magentite filters have been used following secondary treatment process to remove suspended matter and "polish" the effluent.



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Solids removal is accomplished in the upper portion of the Spiragester by spiral downward flow of the influents introduced tangentially into an annular race, and enters clarification compartment at bottom. Diffusion is slow, uniform.

Settled solids in the clarification section enter the digestion compartment, mix actively with digesting material and are attacked by organisms which stabilize the sludge.

In the layout illustrated, secondary treatment is provided by a high capacity trickling filter and final sedimentation by a Spiraflo clarifier.

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TRICKLING FILTERS

TRICKLING filters (also termed sprinkling or percolating filters) consist of beds of broken stone, slag, hollow tile, or other material from 2½ to 4 in. in size. Beds are usually 6 to 8 ft deep but may be 3 ft or 10 ft deep, depending on various factors of design. The stone or other material is laid above an underdrain system, which provides for both rapid discharge of the liquid and ventilation.

Application of the sewage to the surface of the filter may be as a spray from fixed nozzles or from travelling distributors, either rotary (reaction or power driven) in circular beds or bridge type in rectangular beds. For spray nozzle application, the sewage is discharged by automatic dosing apparatus to obtain uniform distribution over the bed surface. The filter is alternately dosed and rested with the resting period being the longer of the two. In travelling distributors, dosage is equal and constant over the diameter or width of the bed; the resting period of any cross section of the bed is equal to half the time for the full cycle of the distributor movement.

As sewage flows downward through the filter it passes over large surface areas of rock covered with biological growths, or slimes. Colloidal and suspended and dissolved organic matter and bacteria are adsorbed on these slime surfaces, thus stripping the sewage of its putrescible load. These adsorbed substances are then decomposed by microorganisms in the slime and reduced substances are oxidized. Carbon dioxide, water, nitrates and nitrites are produced and washed from the slimes by subsequent passage of liquid.

The rate of application of sewage to a trickling filter is determined by two factors: hydraulic loading and B.O.D. loading. Standard rate filters are usually loaded at rates of 1.5 to 3.0 mgd per acre but this hydraulic loading cannot be independent of the B.O.D. loading which should be less than 1000 lb of B.O.D. per acre-foot per day. Under these conditions of loading, standard rate filters will remove from 70 to 90 per cent of the applied B.O.D.; the higher efficiency prevailing for lower B.O.D. loadings.

High Rate Filters

High rate trickling filters are designed to operate at hydraulic loadings of 15 to 35 mil gal per acre per day with B.O.D. loadings of 3200 to 4800 lb per acre-foot per day (i.e. 2 to 2.5 lb per cu yd of stone.) There are three types of high rate filters on the market; "Bio-filter" (Dorr Co.), "Aero-Filter" (Yeomans Bros.) and "Accelo-Filter" (Infilco-Inc.).

The "Bio-Filter" is relatively shallow; all or part of the effluent from the filter is recirculated back to the influent to the primary sedimentation tank. The liquid which is recirculated may be taken from the underdrains of the filter or from the secondary clarifier. Since this liquid contains some dissolved oxygen, its return to the primary tank reduces the B.O.D. of the raw sewage in proportion to the weighted volumes of raw sewage and recirculated effluent.

Installations where strong raw sewage exists, may use two-stage biofiltration, although the total filter volume is the same as a single stage. In two stage biofiltration, recirculation is used for each stage. B.O.D. removal in single stage biofiltration may be from 80 to 90 per cent; two stage biofiltration may produce 95 per cent B.O.D. removal.

The *"Aero-Filter"* has a special distributor with many outlets designed to give high rate momentary distribution over the entire filter surface. Recirculation takes place from the final (secondary) clarifier effluent to the influent to the filter at a rate to insure a minimum hydraulic loading of 10 mgd per acre. Two stage aero-filters produce better B.O.D. removal than single stage, especially when 60 to 65 per cent of the filter media is in the first stage.

The *"Accelo-Filter"* circulates effluent from the bottom of the filter directly back to the top of filter, through the distributor arm. This principle has been applied both to standard rate and high rate filters. For domestic sewage, B.O.D. loadings of 2420 lb per acre-ft per day (1.5 lb per cu yd) are possible in single stage operation where recirculation rates are 100 to 200 per cent of the raw sewage flow. In these filters, stone sizes of 4-in. is preferable and hydraulic loadings are maintained at less than 30 mil gal per acre per day.

There are other trickling filters in addition to those mentioned. The Dorr "Duo-filter" is a two stage filter concentrically arranged. Another trickling filter system is termed "alternate double filtration"; used mostly in England it is a two stage filter arranged to permit reversing the filter sequence so that each filter may alternately serve as the first stage. It has been found that this arrangement produces better results than single stage or ordinary two stage operation.

Secondary Clarification

In trickling filters, the organic matter of the sewage is converted into micro-biological protoplasm. This appears as slime growth on the surface of the stones. Some of this growth washes off with each application of sewage. In standard or low rate filters, the slime growth sloughs off in large quantities at autumn and spring seasonal changes. This action is termed unloading. In high rate filters, unloading is relatively constant. For all types of filters, a sedimentation tank follows the filter to allow removal of this humus discharge. These tanks are termed secondary clarifiers or final tanks. The humus sludge from these secondary settling tanks may be removed and dumped for fill or more commonly in modern practice is transferred to sludge digestion tanks.

Aids to Trickling Filters

As pointed out in the discussion of secondary treatment process, several aids are available to improve operating results. Roughing filters reduce shock and overloads. Chlorination before trickling filters reduces ponding and filter flies. Magnetite filters have been used to "polish" the effluent from trickling filters.

Small Plants

Small trickling filter plants, complete, (for example Yeomans Bros. "Water Wheel Distributor") will handle as little as 1200 gal per day. Pacific Flush Tank Co. makes distributor nozzles for from 5 to 15 persons. High rate trickling filter equipment is available for flows as low as 25,000 gal per day. The two-stage Dorr "Duo-Filter" is available in small capacities. The Dorr "Clarigester", a mechanical Imhoff tank, with a Bio-Filter has been used for populations of 2500.

"Package" plants for 25 to 500 persons are manufactured by a number of firms. In some of these "package" plants, primary sedimentation and digestion as well as secondary treatment is employed and the whole "package" fitted into a minimum of space and designed to operate with a minimum of attention.

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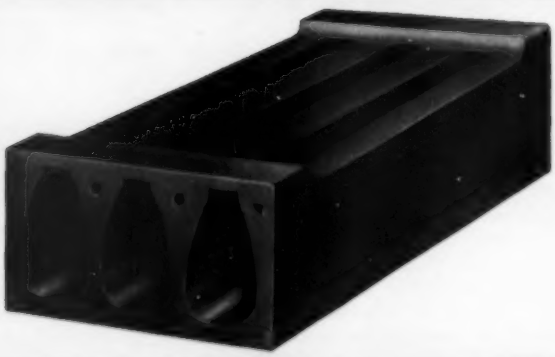
Close-up view of filter bed showing filter media directly on top of Unifilter Block Underdrain Floor at Sewage Treatment Plant in Worcester, Mass.

NATCO salt glazed UNIFILTER underdrain BLOCKS



Whether it's strength, acid and corrosion resistance, durability, low absorption, rapid flow characteristics—NATCO UNIFILTER salt glazed underdrain blocks more than meet the requirements. They provide maximum drainage and ventilation capacity for either standard or high rate trickling filter sewage treatment plants. Moreover, they are easy to handle, easy to lay, and they are chemically inert and permanent in form.

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High-Rate Filter Performance*

by F. W. MOHLMAN
Director of Laboratories, Sanitary District of Chicago

IT IS unfortunate that the development of high-rate filters has been so competitive, because each company promoting a certain type of filter has been interested in giving publicity to results of operation that apparently show the superiority of the company's type of filter. Certain helpful developments have occurred, such as approximately continuous dosage, recirculation, use of coarser media, uniform volumetric dosage and continuous discharge of flocculated solids, but many of the curves, formulae and assumptions derived from filter operation actually rest upon a deficiency of the B.O.D. determination; namely, that the same 5-day B.O.D. result can be obtained whether or not there is nitrification of the applied ammonia nitrogen.

The writer makes no claim that it is necessary to oxidize the ammonia nitrogen, with reference to conditions of disposal, but from the standpoint of work done by the filter it makes a lot of difference whether the treated effluent is in the first or second stage of the B.O.D. curve, and filter volume giving low rates of application is necessary if one wants to accomplish complete treatment by a filter.

Early Investigations

The Sanitary District of Chicago became interested in high-rate filters in 1935 and Halvorson's filter in Minneapolis was visited, followed by the installation of an experimental 20-ft. filter in Chicago. Later a Jenks two-stage shallow filter was operated for two years. The summarized results of operation of these filters are shown in Table I.

At rates of 28 mgad. the B.O.D. in the effluent was 31 to 44 ppm., corresponding to about 50 per cent reduction from the influent, and suspended matter in the settled effluent ran from 28 to 54 ppm. Later, the shallow recirculated filter, at a rate of 21 mgad., yielded an effluent containing 31 ppm. B.O.D. and 37 ppm. susp. solids, removing 1,347 lb B.O.D. per acre-ft. and producing 3.6 ppm. nitrate plus nitrate nitrogen.

The best of these results, however, was far from satisfying the requirements of dilution imposed upon the District by the Supreme Court, so high-rate filters were abandoned in favor of activated sludge treatment, which produces effluents with only 8 to 15 ppm. B.O.D. and corespondingly low suspended solids.

As the years have passed, numerous contributions have been made by the promoters of high-rate filters, with all possible consideration of the favorable factors. It is quite evident that a renaissance has occurred in the theory of biological filtration as exemplified by trickling filters, namely, the principles of low-rate application of load by nearly continuous coverage of surface "raindrop" application, uniform unloading of solids, thorough secondary settling, recirculation of all varieties, and improved dosing apparatus.

Recent Studies

Many investigations have also been made by disinterested parties, such as the Walton investigations sponsored by the state sanitary engineers of the Upper Mississippi Basin, the summarized results reported by Dreier (Sew. Wks. Jour., July, 1946; *Water and Sewage Works*, Jan., 1947) and the report of the National Research Council on "Sewage Treatment at Military Installations" (Sew. Wks. Jour., Sept., 1946).

The trickling filter results in the latter report were re-arranged in Tables VIII, IX, X and XI of the concluding summary report compiled by the NRC Subcommittee on Sewage Treatment in Military Installations and published in the January, 1948 issue of Sew. Wks. Jour. The tables group the data for four classes of filters: (1) deep, with no recirculation, (2) deep, with recirculation, (3) shallow, with recirculation, and (4) two-stage. The plants are arranged in the order of filtration loads, and some nitrification results are shown. Reference is made to these tables in the following discussion.

Table VIII in the summary report (Sew. Wks. Jour., Jan., 1948, page 73) shows the first series. These filters were all about 6 ft. deep and in most cases the load was quite low. Thus they could be classified as standard-rate trickling filters.

At loadings up to 720 lb. per acre-ft., except for the Fort Sheridan filter, the filters plus secondary settling tanks removed 85 to 92 per cent of the applied B.O.D., and the overall removal varied from 91.5 to 95.0 per cent. Fort Sheridan gave anomalous results, showing poor removals probably because of excessive primary settling period, pooling, and high application rates resulting from excessive resting periods. Nozzles discharged only 4.5 minutes out of 25, giving a very high momentary rate.

Nitrification continued quite well up through the loading rate of 377 lb. B.O.D. per acre-ft., but fell off at 429 and especially at 720 lb. per acre-foot. The low degree of nitrification at Ft. Benjamin Harrison—only 1.5 ppm. ntrite plus nitrate nitrogen—appears questionable with the 429 lb. loading, since the ammonia N decreased from 21.1 ppm. in the influent to the filter to only 6.1 ppm. in the filter effluent. Since surely more than 1.5 ppm. of this loss was nitrified it may be concluded that nitrification was active up to 720 lb. loading of B.O.D. per acre-foot.

The second series of filters (Table IX, NRC summary report, Sew. Wks. Jour., Jan., 1948, page 74) shows results for eleven plants, with loadings from 245 to 5,750 lb per acre-ft., and recirculation of from 24 to 358 per

TABLE 1
Sanitary District of Chicago High-Rate Filter Studies

Type Filter	Period of Operation	Rate (m.g.a.d.)	Recirculation (%)	Lb. B.O.D. Removed per Acre Ft.	B.O.D. (p.p.m.) Filter Inf.	B.O.D. (p.p.m.) Final	B.O.D. (p.p.m.) Efficiency (%)	Susp. Solids (p.p.m.) Filter Inf.	Susp. Solids (p.p.m.) Final	Susp. Solids (p.p.m.) Efficiency (%)	Nitrate + Nitrate N (p.p.m.)
Deep	Year 1937	27.7	0	1,187	72	31.1	57	74	31	57	1.8
Shallow	Year 1937	28.7	217	1,079	73	44.3	39	74	54	27	1.9
Deep	Aug.-Dec., 1937	28.3	0	1,198	73	35.2	52	73	28	62	2.5
Shallow	Aug.-Dec., 1937	21.1	231	1,347	73	30.6	58	73	37	49	3.6

*Reprinted from Sew. Wks. Jour., Vol. 20, p. 618, by permission.

TABLE 2

Summary of Trickling Filter Plant Operation

No. Plants	Group Designation	Range of B.O.D. Loading (lb./acre ft.)	B.O.D. Efficiency, Filter and Sec. Settling (%)	Overall B.O.D. Reduction (%)	B.O.D. Remaining (%)
4	Deep, No Recirc.	253 to 429	86.9	92.2	7.3
4	Deep, Recirc.	245 to 1170	85.7	90.8	9.2
8	Two-Stage	192 to 930[1]	66.5[1]	90.2	9.8
4	Shallow, Recirc.	792 to 2320	81.8	88.1	11.9
4	Deep, Recirc.	1100 to 1950	78.7	87.5	12.5
3	Deep, No Recirc.	720 to 2130	75.7	82.8	17.2
3	Deep, Recirc.	2530 to 5750	70.3	78.3	21.7
4	Shallow, Recirc.	2370 to 8250	70.1	74.8	25.2

[1] Second stage.

cent of the applied volume. Of the first four plants, Gordon was not very effective in removal of B.O.D. but removal of suspended solids was excellent. Leaving out this plant, the overall removal of B.O.D. was around 93 per cent, up to a loading of 1,170 lb. B.O.D. per acre-foot.

The next four plants were loaded up to 2,000 lb. per acre-ft, and gave decreasing removals and practically no nitrification. Forrest and Jackson, at 2,530 and 2,870 lb. loading, gave decreasing removals, but Callan, at the enormous loading of 5,750 lb., gave good removals. This was the prize camp in operation, possibly due to very good secondary settling, which reduced the B.O.D. from 118 ppm. in the filter effluent to 77 ppm. in the final effluent. Good flocculation and low overflow weir rates probably responsible for the high removal. The camp was located in Southern California.

Table X in the NRC summary report (Sew. Wks. Jour., Jan., 1948, page 76) shows results for shallow filters, with high rates of recirculation. The four plants, except Kearns, gave poor filter results due to excessive growths of fungus on the filters.

The other three plants gave high B.O.D. removals up to 2,320 lb. loading, but obviously with no nitrification. Kearns gave 11.3 ppm. nitrate plus nitrate N and with 792 lb loading, but with excessive recirculation far beyond the bonds of economy.

The last four plants gave poorer results, down to 58 per cent overall removal (first-stage) at Frances Warren, the most heavily loaded filter included in these studies. This was only the first stage, the final effluent from the second stage being reduced to 66 ppm., an overall removal of 84.8 per cent. Plant efficiency was reduced by return of a heavy supernatant liquor, and also because of the severe Wyoming winter weather.

Results for two-stage filters are given in Table XI of the NRC summary report (Sew. Wks. Jour., Jan., 1948, page 77). These results were all good at moderate loadings except Warren, which was somewhat inferior for reasons given above. With the very high loading of 5,280 lb, Camp Roberts gave quite inferior removals.

Discussion

The individual results in Tables VIII to XI of the NRC summary report have been summarized in various groups in Table II, with increasing loadings from 253 to 8,250 lb. per acre-foot. The first group, deep filters without recirculation, gave 93 per cent overall reduction and is characterized by high nitrification and low volumetric and organic loads applied.

Next, recirculation enables the loads to be increased to 1,170 lb per acre-ft., and in general results improved as recirculation ratios increased. At Boca Raton a filter rate of 14.9 mgad. plus 358 per cent recirculation gave an effluent with only 16 ppm. B.O.D.

Recirculation thus improved considerably results from a deep filter at 1,170 lb per acre-ft. application, but the rate of recirculation seems too high for such a dilute sewage.

Next, two-stage filters gave excellent results but most of the work was done in the first stage.

For higher loadings, up to around 2,000 lb. per acre-ft., shallow filters with considerable recirculation (from 280 to 1,050 per cent) were able to produce around 90 per cent overall reduction of B.O.D. and, at Kearns, considerable nitrate with the highest rate of recirculation.

A mathematical analysis by Dr. Thomas (Sew. Wks. Jour., Sept., 1946, page 975) indicates that an 800 per cent recirculation rate gives the maximum increase in capacity of high-rate filters.

Finally, at high rates of loading, from 2,370 to 8,250 lb. per acre-ft., results were quite inferior to those produced by a standard low-rate filter.

It is interesting to note that loadings above 2,000 lb. per acre-ft. resulted in effluents containing around 70 ppm. B.O.D., overall removals of 78 per cent, and no nitrification. This is far from the quality of an effluent from standard low-rate filter operation, even though the loading is less than the 3,000-lb. rate used in design of high-rate filters.

None of the filters loaded at over 2,000 lb. B.O.D. per acre-ft. produced nitrification. For the period during which nitrogen tests were made, some of the results are shown below:

It will be noted that the ammonia nitrogen shows very substantial reduction in the lightly loaded plants, with corresponding high nitrates in effluents. For single-stage plant, at loadings in excess of 974 lb., ammonia is reduced very little and there are no nitrates. Two-stage plants show nitrates.

Considerable oxidizing intensity is necessary to promote nitrification. The ammonia present requires 4 oxygen to 1 nitrogen, or 4.56 times the decrease in ammonia nitrogen. This can require considerable air in activated sludge treatment, or filter surfaces, for oxidation, and therefore the dosing rates must be low if nitrification is to occur.

It seems difficult to believe, therefore, that effluents from high-rate filters, dosed at rates higher than 1,000 lb. B.O.D. per acre-ft. per day, are just as completely treated as effluents from standard low-rate filters. There is a fallacy in using only the 5-day B.O.D. to measure the results accomplished.

For many conditions of disposal, however, a nitrified effluent is unnecessary, and for such conditions, intermediate grade effluents will suffice, such as those from chemical treatment as well as from high-rate filters. For Army camps, urgent as well as temporary, such filters were highly satisfactory. Are they as satisfactory for permanent use in municipal installations?

Post	Lb. B.O.D. per Acre-Ft. per Day	Ammonia Nitrogen as N (p.p.m.) Influent to Filter	Final Eff.	Nitrite + Nitrate N (p.p.m.)
Campbell	172	29.1	3.9	17.4
Fitzsimons G.H.	283	19.9	12.1	0.9
Benj. Harrison	199	21.1	6.3	1.5
Swift	197	27.4	9.7	11.8
Leonard Wood	256	44.2	9.2	19.5
Carson	320	14.3	8.0	2.0
Drew Field	974	25.1	18.2	0.9
Jackson	2930	29.0	20.4	0.8
Knox	1563	15.7	13.4	1.9
Bragg	3900	33.5	32.0	Tr.
Kearns AAF[3]	678	26.0	22.0	12.3
Gordon[2]	392	22.6	16.6	5.0
F. E. Warren[2]	980	46.1	21.9	7.0
Claiborne[1]	1040	32.0	24.0	1.2

[1] First-stage.
[2] Two-stage.
[3] Recirculation, 1,050 per cent.

part of it, and must do its share in removing the settleable material in the filter effluent.

Media size and type for best treatment results have not been determined. A careful study of filter operating results does not give any conclusive basis for design. There is general agreement that the stone should not be too small, nor too large. Probably 2½- to 3½-in. or 3- to 4-in. represents good general practice and is desirable. The writer's preference would be for the larger stone, even in the secondary units of two-stage filters. Tile media have not been widely used, but should certainly be considered for strong sewages. According to Banister and Ellison (6), tile block is a "uniform material, permanent in character and self-cleaning. It will not pond. The normal design loading for a tile media high-rate filter is about 3.33 lb. per cu. yd. of media, permitting the use of a unit 10 per cent of the size of a low-rate filter. . . . The small size . . . permits economical housing, thus providing odor control, fly control and better treatment during the winter months." When a high degree of treatment is required and the final effluent must have a low B.O.D. content, these high-rate filters are followed by low-rate filters with stone media.

It is likely that two-stage filtration will become more general, with the use of high-rate filters as roughing filters carrying a very heavy load, and with final treatment by secondary high-rate filters, low-rate filters or activated sludge. All these methods are now in use, and with good results. The selection among them should be largely a matter of local conditions.

It appears reasonable to say, as regards high-rate filters, that a sound basis for design exists, but there is no explanation of the fact that some installations perform in a superior manner. It has been a matter of interest to the writer to investigate much of the data available to determine whether media size, underdrainage provisions, the character of the water as respects pH and alkalinity, and various other factors might have an important influence. None of these, with the possible exception of underdrainage and ventilation, appears to have any effect on the quality of the effluent from a trickling filter.

Perhaps it goes back to what F. H. Waring terms the "treatability of the sewage." That may be reflected in the B.O.D. characteristics of the sewage and the rate of biochemical oxidation. The NRC report brought out the varying values of k in military sewages. The average value of k for domestic sewage is 0.10, but the average value for the sewages at 16 military posts was 0.18. With k equal to 0.10, the 5-day B.O.D. represents 68 per cent of the ultimate B.O.D., but when k equals 0.18, the 5-day B.O.D. represents 87.4 per cent of the ultimate.

Thus, the B.O.D. test may be a varying rule for measuring operating characteristics, with naturally varying results. It seems unlikely, however, that this is the sole reason for the variations in performance noted at different plants. Uniformity of loading and of sewage application is probably a factor of at least some importance. Study of the other factors in design or operation that so markedly influence operating results furnishes an enticing field for future research and investigation.

References

1. *Sew. Wks. Jour.* 18, 5 (Sept., 1946).
2. *Public Works*, 78, 5 (May, 1947).
3. *Ibid.*, 6 (June, 1947).
4. *Ibid.*, 7 (July, 1947).
5. Unpublished data, Pacific Flush Tank Co.
6. *Public Works*, 78, 9 (Sept., 1947).

Discussion

By W. A. HARDENBERGH

Editor, Public Works Magazine, New York City

THE performance of high-rate trickling filters is a matter of record. Somewhat over a hundred such filters were built to serve military establishments during the war. On these, there are available the excellent data prepared by the National Research Council Sub-Committee on Sewage Treatment at Military Installations (1). Operation records on many of the high-rate filters used by municipalities and industries are also available, but these data are not generally so complete and authentic as those from the military establishments.

There are four types of high-rate filters. They are described, in the words of the manufacturers or their representatives, as follows:

"Biofilter (2) is a term applied to high-rate filters, normally comparatively shallow, which employ . . . the recirculation of all or part of the filter discharge back to the detention tank. The recirculated filter discharge may be filter effluent, or secondary clarifier contents, underflow or effluent."

Aero-Filters are "one classification of the 'high-rate' trickling filter group" having "a low momentary rate of sewage application whereby a high daily capacity for B.O.D. reduction is obtained." This process (3) "applies the sewage over the media in a very thin film. . . ." In the Aero-Filter recirculation is used at periods of low sewage flow in order to maintain a minimum necessary rate of application at which the distributor will function properly; it is also beneficial for treating strong wastes.

"The Accelo-Filter system (4) involves the direct recirculation of unsettled effluent from a biological filter back to the inlet of the filter distributor. This process may be used with either low-rate or high rate filters."

"Reversible double filtration (5) consists of two trickling filters arranged to be operated for two-stage filtration with provision for reversing the sequence of the filters so that each may alternately serve as the primary and the secondary filter. This will allow the primary filter to be utilized with maximum effectiveness by applying, for short periods, loadings approaching the limit of the capacity of the filter. The secondary filter meanwhile will operate under much reduced loadings. . . ."

Loadings for high-rate filters are now quite well established in the range of 3 lb. of raw sewage B.O.D. per cubic yard of stone per day. With the reduction obtained by primary treatment, the applied B.O.D. is generally designed to be a little less than 2 lb. per cu. yd. or about 3,000 lb. per acre-foot. There is evidence, however, that heavier loadings are possible when recirculation is employed. In the experimental work done by the U. S. Public Health Service at Neosho, Mo., loadings in excess of 2.5 lb. of B.O.D. per cu. yd. were applied with no indication of a break from the straight-line trend of removal. Banister and Ellison (6), using tile media for the treatment of strong sewages containing milk, packing and canning wastes, report a normal loading of 3.3 lb. of B.O.D. per cu. yd. of media with a B.O.D. removal of 70 to 75 per cent; and nearly straightline removals up to 6 lb. or more per cubic yard. With stone media, they report a critical loading of about 4.5 lb. of B.O.D. per B.O.D. Normally recirculation will

be required to dilute the settled sewage to this strength.

Two-stage treatment will accomplish remarkable results, even with heavy loadings. Camp Roberts (1), with a loading of 8,680 lb. per acre-ft., or more than 5 lb. per cu. yd. of filter, produced an effluent with an average strength of 53 ppm.; Fort Warren with a loading of 8,520 lb. per acre-ft. produced an effluent with 66 ppm.; and Fort Sill, with a loading of 6,440 lb., or 4 lb. per cu. yd., had an effluent with 26 ppm. of B.O.D.

The 1-mgd. plant at Liberty, N. Y., a two-stage biofilter, was designed to handle a raw sewage loading of 3.1 lb. per cu. yd. of media. In July, 1944, the average flow was 1.29 mgd.; the average raw sewage B.O.D., based on composites from 8 a.m. to 2 p.m., was 520 ppm., representing a 24-hour composite of probably 360 to 370 ppm.; and the average effluent from the secondary clarifier (9 a.m. to 3 p.m. composite) contained 21 ppm. B.O.D. The actual effluent B.O.D. content during this month averaged slightly less than 6 ppm., the secondary clarifier effluent being passed through a magnetite filter and chlorinated befor discharge into the stream. The results for 1944 are about the same as those that have been attained consistently ever since the plant was put into operation in the fall of 1940. Operation is by one man, which accounts for the daytime tests. During the winter, the plant is operated without recirculation as a conventional trickling filter, with satisfactory results, since the population load is then much lower, Liberty being a summer resort.

There is a need for more knowledge about the requirements for underdrainage and ventilation in filters. Certainly, adequate provision should be made to remove the liquid promptly and to provide air to the bed, not only when the plant is new but also after it has been in service for many years and has accumulated a considerable organic growth. Those who have had the experience of removing the stone from an old filter will appreciate the amount of material that is found in them, especially in the bottom few inches through which the filtrate must pass and air must enter.

Pretreatment should be the best that can be provided. Anything that can be removed by settling results in that much less load on the secondary treatment units. The necessity for good design and adequate provision in final settling is just as great. It is well to remember that the clarifier following the filter is essentially a cu. yd., with removal consistently less than for tile.

Two of the plants noted in the NRC report were loaded considerably higher than the limits indicated above. Camp Callan, a deep filter employing recirculation, had an average applied loading of 5,750 lb. per acre-ft. or more than 3.5 lb. per cubic yard. Removal was 4,280 lb. per acre-ft., or 74.5 per cent. The Fort Bragg filter, a shallow unit, had an applied load of 4,340 lb. of B.O.D. per acre-ft., or about 2.7 lb. per cu. yd., and gave a removal of 80.7 per cent. Both of these plants employed recirculation. The Great Lakes plant, a deep filter without recirculation, had a loading of 2,130 lb. per acre-ft., or 1.3 lb. per cubic yard. Removal was 71 per cent.

Since B.O.D. removal is proportional to the load applied, a higher B.O.D. loading will always result in an effluent containing a higher concentration of B.O.D. This applies to any particular process, but by means of recirculating or two-stage treatment much better results can be obtained than with a single passage of the sewage through the filter. Single-stage high-rate filters without recirculation may accomplish a removal of 70 per cent of the applied B.O.D., or sometimes a little better. With an applied sewage of 200 ppm., this means an effluent with about 60 ppm. To obtain an effluent containing only 30 ppm. of B.O.D., with the relatively standard loading of 3,000 lb. per acre-ft., or 1.86 lb. per cu. yd., recirculation is necessary. According to Gloppen (3), in order to maintain an effluent of 30 ppm. B.O.D., the applied sewage should not exceed 135 ppm.

ACTIVATED SLUDGE

THE ACTIVATED sludge process of secondary treatment differs from trickling filter operation in that precipitation and oxidation takes place on the extensive surfaces of active biological flocs which are maintained in suspension in the sewage being treated. These biological flocs, which are termed, "activated sludge," are moved freely through the liquid, either by mechanical mixing or by agitation with air bubbles. This agitation brings air in contact with ever changing surfaces of water, and dissolves oxygen in the liquid, thus becoming available to the organisms in the free floating activated sludge floc.

As organic matter is adsorbed and decomposed on the floc, the floc grows in quantity and volume; therefore some of the sludge must be wasted. Following the aeration period, the mixed liquor of sludge and treated sewage passes to a secondary clarifier, where the sludge settles. A portion of this settled sludge is returned to the inlet end of the aeration units where settled sewage is also added and excess sludge is pumped to the sludge disposal process.

Plant Characteristics

Activated sludge plants require relatively small land area and construction costs are lower than for trickling filters. Operation costs, however, are higher than those of trickling filters because of the power requirements for aeration. Tanks for aeration are usually 15 ft deep and long and as wide enough to produce the required aeration time.

Diffused air may be added from porous plates or tubes, impingement aerators, jet aerators, fabric diffusers, etc. The air is introduced in such a manner as to create a spiral flow of sewage through the tank. Air blowers and air filters are required. In another method of aeration air enters from a central rotating shaft near the bottom of a tank and is dispersed by a rotating paddle device ("Cavitator").

Mechanical aerators are either paddle or vertical draft tube. In the former, a paddle wheel or brush revolves on a horizontal axis and is partly submerged in the sewage. In the latter, sewage is drawn up (or down) through a central tube by means of a revolving impeller, which provides both agitation and aeration.

Operation

Activated sludge plants generally produce better results than trickling filters but require more attention and control. There should be some dissolved oxygen present in the influent end of the aeration tanks and at least 2 ppm in the effluent from the aeration tanks.

Aeration periods vary from 3 to 12 hours (common 4 to 6 hr) depending on the installation, B.O.D. load, etc. Air consumption varies from 0.35 to 1.7 cu ft per gal of sewage (common 0.7 to 1.2). Solids carried in the aeration tank (termed mixed liquor solids) vary from 700 to 4000 ppm (normal 1000-2000 ppm). On the average, activated sludge plants may be expected to produce an effluent (after final settling) with 10 to 20 ppm of suspended solids and 8 to 18 ppm of B.O.D. The stronger the sewage load, the higher the removal of solids and B.O.D.

The quantity of excess sludge removed is equal to 1 to 1½ per cent of the volume of sewage treated. The volume of sludge returned to the aeration tanks is from 15 to 40 per cent of the final clarifier sludge, and will depend on concentration of sludge solids in the final sludge and desired concentration of suspended solids in the aeration tank.

One of the problems is sludge bulking, wherein the sludge fails to settle properly in the final tank and goes out over the weir. Bulking may be controlled by chlorination and by controlling the sludge index (weight of sludge per unit volume) plus tests on the activity of the sludge (i.e., its oxygen consumption per unit weight per unit time). Most mechanical aeration plants are relatively small installations.

Modifications of Process

Tapered aeration is a method of controlling the input of air (oxygen) at various points in the tank (more air being added at the influent end) so that the aeration rate is tapered or regulated by determining the "Nordell Number" (quantity of oxygen utilized in ppm per hour by weight).

Step Aeration is a modification, whereby the sewage is introduced at multiple points throughout the course of the flow of the returned sludge through the aeration tanks. Other terms for this method are "distributed loading," "multiple-point dosing," and "incremental feeding."

High Rate Activated Sludge Treatment, or "modified aeration," consists of short aeration periods and relatively small amounts of return solids. This method is intermediate between primary sedimentation and high rate single stage trickling filters or activated sludge. The degree of treatment is controlled by the air supply, aeration period, and amount of returned solids (usually 600 to 900 ppm). Low air supply, small tank capacity and dense excess sludge are possible.

Proprietary Processes

Bio-chemical Process is the trade name applied to the Guggenheim process, which employs the addition of a coagulant (iron salts or alum) in the activated sludge process, the coagulant being added together with the return sludge to the aeration tank.

P.F.T.-Kraus Process, or the "digester liquor nitrification process", operates on the principle of correcting the carbon-nitrogen ratio in the food supply for the micro-organisms. Digester liquor or digested sludge (or a combination) is mixed with return activated sludge and this mixture added to one or more aeration tank units. The high ammonia content of the digester liquor or sludge is oxidized to nitrites and nitrates and the density of the sludge is increased in proportion to the amount present of digested sludge of higher specific gravity.

Oxidized Sludge Process (Mallory process) was a term given to what was essentially a control process for the activated sludge system.

Patented Process and Equipment includes the "Aerator-Clarifier" (Chicago Pump Co.); "Dorrco Aerator-Clarifier" (Dorr Co.); "Aerifier" (Yeomans Bros.); "Currie Claraetor (Dorr Co.); "Process Oxidator" (P.F.T. and Process Engrs.), all of which combine mechanical aeration with a clarifier in one unit.

Other combination processes include "Bio-activation," a combined high rate trickling filter and activated sludge (American Well Works); "Aero-Accelator" (Infilco, Inc.) in which a high rate activated slurry biological treatment is effected; "Accelo-Biox" process (Infilco, Inc.) which involves the direct recirculation of mixed liquor through the aeration tank of an activated sludge plant, and "Biosorption" process (Infilco, Inc.) in which raw sewage is mixed with activated sludge and settled, the sludge then being aerated.

"Bio-precipitation" employs oxygen (95 per cent pure) for oxidation by an active biological sludge. The process employs counter current flow of sewage.

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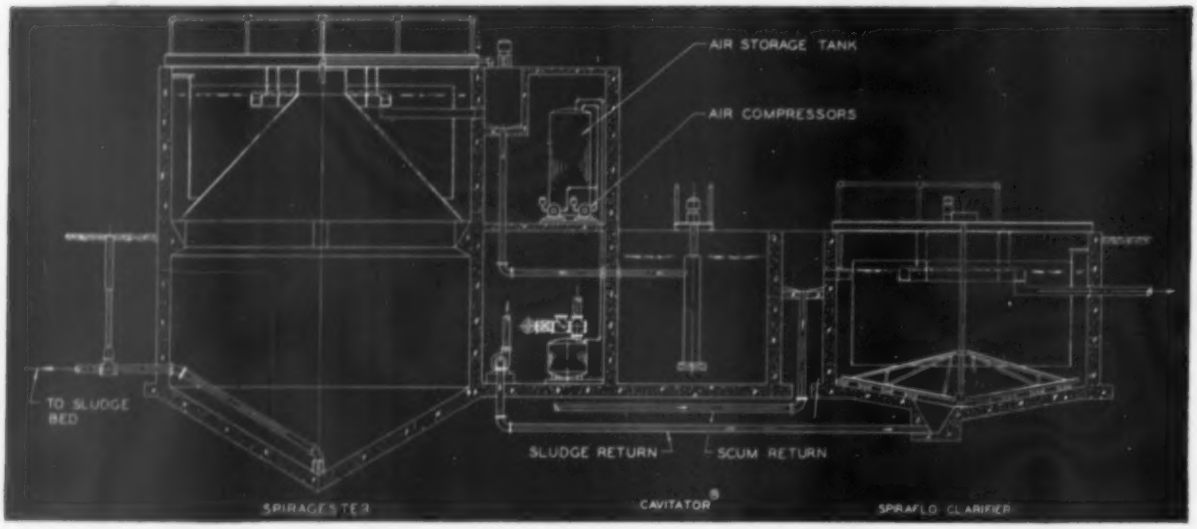
THE Cavitator* SYSTEM

For Municipal Waste Treatment



One of the many possible arrangements is illustrated. The secondary treatment is provided by the cavitator mechanism, a specially designed rotor with two arms mounted on a hollow shaft through which the air is drawn for dispersion through the tank contents. The arms are streamlined with the outer arms so constructed that when they are passed through the liquid at relatively high speeds they create a zone of cavitation through which the liquid is recirculated continuously. Air and liquid are drawn together creating a vapor pressure condition corresponding to cavitation with its tremendous forces. The oxygen is forced into the sewage and creates countless small air bubbles which permeate the entire liquid body.

One of four cavitators at New Holstein, Wis. Plant has State approval for municipal waste.

- **high oxygen transfer efficiency**—requires only 135 cu. ft. of air per lb. B.O.D. removal per day in the Cavitator system.
- **high performance on relatively low flows** with high B.O.D.
- **low installation and operating cost** with a high degree of purification.

Primary clarification and digestion is accomplished in a single structure, the Spiragester. A Spiraflo is used for clarification.

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Air Diffuser Maintenance

by FRANK C. ROE

Development Engineer, The Carborundum Company, Perth Amboy, New Jersey

EVER since the successful development of the activated sludge process in 1914, followed by several other aeration processes or beneficial applications of air for sewage treatment (and some water treatment), there has been a constant effort to improve the methods or devices used for aeration. Such progress, of course, is a normal phenomenon when effective and, generally, economical processes have become established. This progress has been based on these equally normal objectives:

1. Desire for increased efficiency (of ozygenation),
2. Desire to reduce maintenance generally and thus minimize cost of aeration.

Pointed towards the first objective of increasing efficiency, many devices and/or methods of aeration have been tried; *some of them more than once*, and several of them patented. A great deal has been written on this subject involving, for example, the relative values of air diffusion and surface oxygenation from the atmosphere, but that comparison is beyond the scope of this outline. A thorough consideration of all ideas leads to two basic conclusions: (1) That diffusion of air bubbles has proved to be the most efficient method of aeration, and (2) that porous ceramic diffusers similar to the type originally found to be most efficient continue as the standard and most satisfactory device or material to accomplish the job.

The greatest increases in oxygenation efficiency have come about by improvement in aeration tank design and diffuser distribution. Specifically, the two major improvements have been: (1) The use of "spiral flow" tanks instead of "ridge and furrow" and (2) the spreading of diffusers to give a wider air bubble column in such spiral flow tanks.

The Maintenance Problem

The second objective of reducing diffuser maintenance is the prime subject of this outline. Basically, it involves keeping diffusers clean so that blower pressures and power cost will not increase unduly. An analysis of plants in service for ten or more years shows that many have required little diffuser servicing. The same survey indicates however, that maintenance of diffusers at a satisfactory level of efficiency frequently is a serious problem.

Figure 1 illustrates the magnitude of blower pressure increase when clogging develops and/or diffusers are not maintained in a clean condition. This was prepared by Superintendent J. J. Wirts of Cleveland's Easterly plant and provided cogent evidence to justify a diffuser servicing program. An analysis of each plant's experience would be too involved for this outline but the marked decrease in pressure loss from the maximum recorded at Cleveland (and elsewhere) indicates the eminent success of such a diffuser servicing program.

Diffuser clogging invariably is caused by one or more of the undesirable conditions that will be described in the following section. *Prevention of clogging usually is possible, as evidenced by the experience at many plants and should be practiced to the utmost within economic limits.* Prevention commences with the original *design* of the diffuser system. A favorable environment can then be maintained by means of good *installation* and *operation*. These three important prerequisites are described in the three sections that follow the outline of clogging sources.

Sources or Causes of Diffuser Clogging

Clogging is experienced on either or both the air and the liquid side of air diffusers.

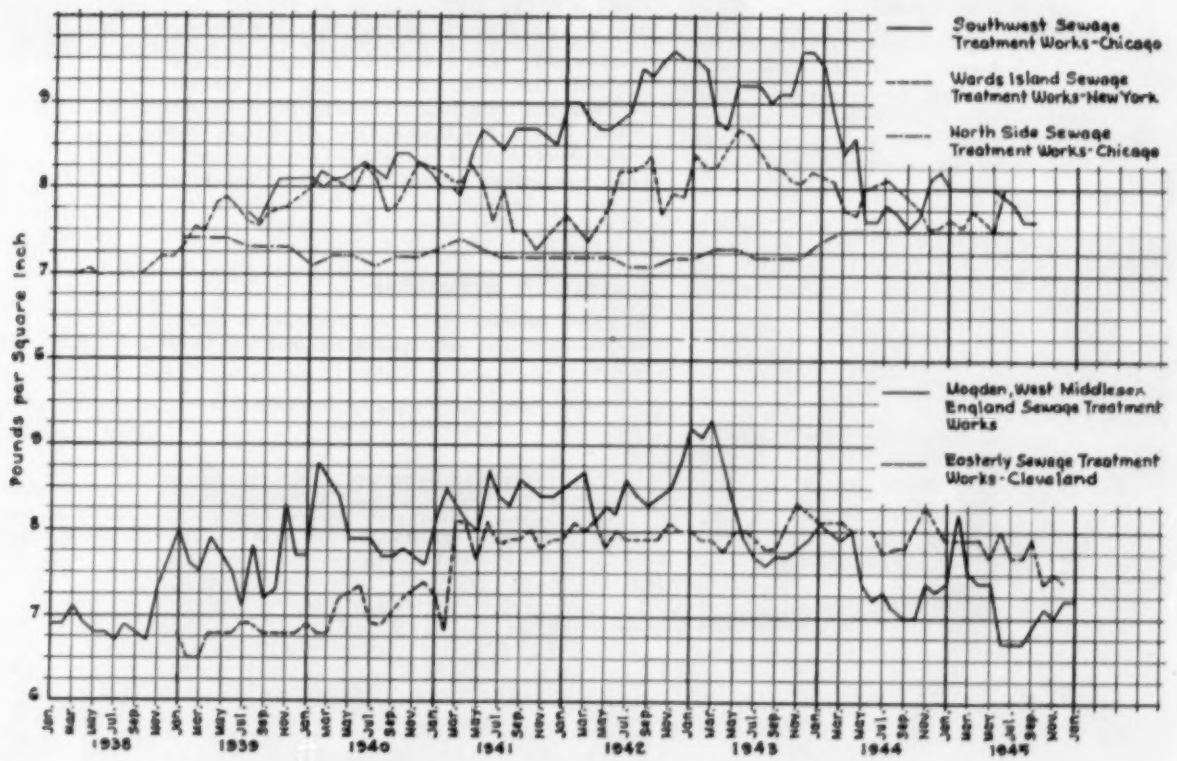

Fig. 1. PRESSURE of air supply to aeration tanks at five plants

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for Sewage and Waste
AERATION

LIFTS UP FOR DIFFUSER MAINTENANCE

Individual Swing Diffusers can be lifted out of tank without interrupting operation, eliminating stand-by aeration tanks. Precision Diffuser tubes are quickly and simply cleaned to new condition to achieve maximum diffusion with low head loss.

Chicago Swing Diffusers offer all sizes of treatment plants—both industrial and municipal—the advantages of air diffusing apparatus that is always in operation at maximum efficiency.

BOOST AERATION CAPACITY AT OLDER PLANTS, BRING HIGHEST EFFICIENCY TO NEW

Wide Band Diffusion provided by Chicago Swing Diffusers in many cases doubles the aeration capacity of previously used plate diffusion systems. For example, the Columbus, Ohio Sewage Treatment Plant was able to treat only 37 M.G.D. with their old diffuser plate system. After changing to Swing Diffusers, aeration capacity was doubled *without increasing the amount of air used or the volume of the aeration tanks.* In both old and new plants, Swing Diffusers assure maximum oxygenation.

FLEXIBLE AIR DISTRIBUTION

Individual Diffusers can be simply adjusted to balance air supply with oxygen demand for effective process control.

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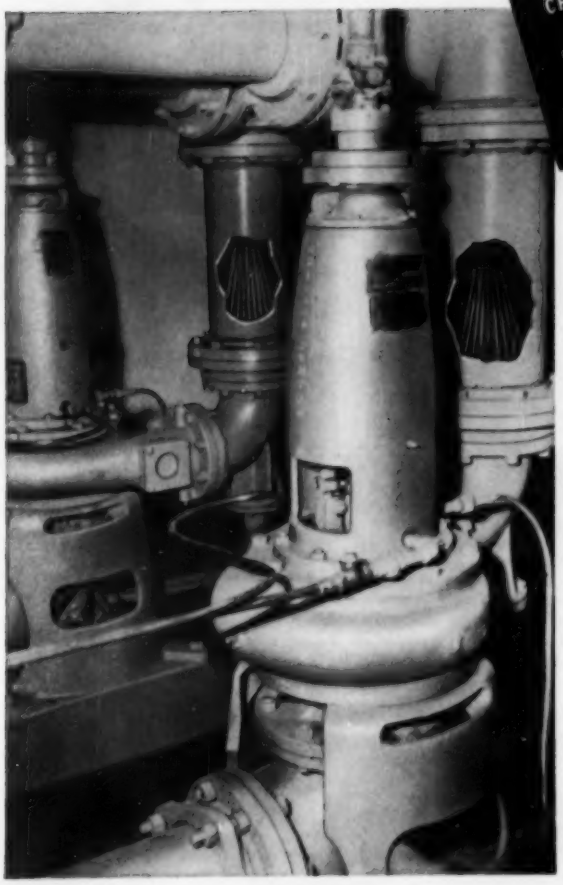
CHICAGO SEWAGE EQUIPMENT

FLUSH-KLEEN® Sewage Ejectors

More than 12,000 installed in lift stations, buildings and ships



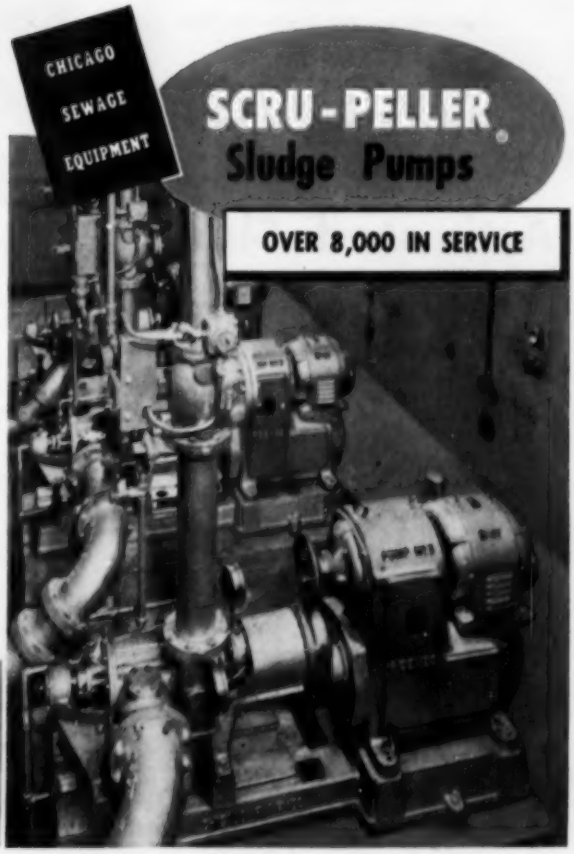
Flush-Kleen sewage ejectors can't clog because rags never reach the impeller. Specially designed strainers in the discharge line retain all coarse matter. Sewage flows over the strainer and through one of the pumps to the wet well. When the pumps operate alternately they pump only strained sewage. No rags or coarse material ever pass through the pump casing. Each strainer is automatically flushed clean during its pumping cycle.

One of 11 Flush-Kleen sewage ejector lift stations installed in the City of Portland, Oregon. The discharge line has been cut away to show the strainer. These stations were designed by Stevens and Koon the Engineers for Portland Sewerage Project.

CHICAGO SEWAGE EQUIPMENT

SCRU-PELLER® Sludge Pumps

OVER 8,000 IN SERVICE



Scru-Peller pumps are designed specifically for pumping primary sludge, are positive in operation and truly clog-proof.

Continuous multiple shearing action is provided by stellited cutting edges of the screw and eight stellited cutting bars positioned in the screw and pump housings.

Heavy-duty ball bearings at each end of the screw and impeller shaft eliminate strain and vibration, permitting pump to withstand sudden and severe overload shocks.

Three of the 27 Scru-Peller pumps installed at the Hyperion Sewage Treatment Plant, Los Angeles, California. Board of Public Works and Metcalf & Eddy, Engineers.

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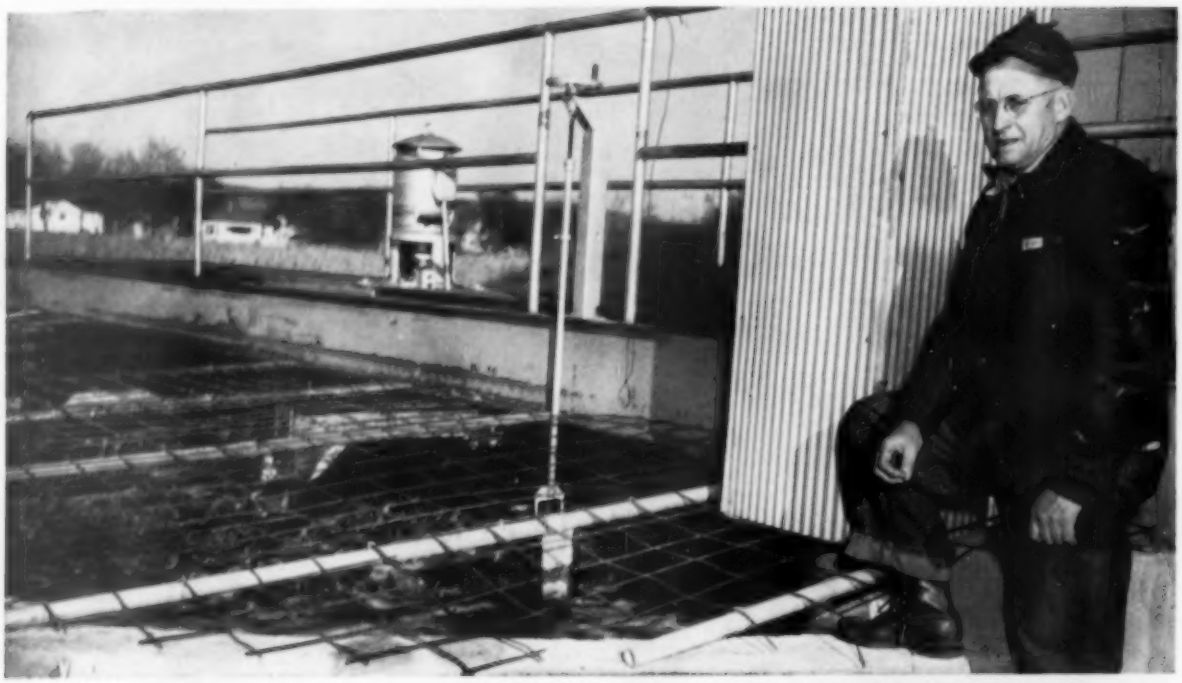

Mr. J. M. Bricker received the award at a recent meeting of the Nebraska Sewage and Industrial Wastes Association. Among other duties for the town of Paxton, Mr. Bricker spends about 12 hours per week looking after the 'Pakage' plant.

SCOTT-WILBUR

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"Sewage Plant Operator Having The Best Maintained And Operated Sewage Treatment Plant in Nebraska During 1954"

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Activated Sludge 'Pakage'* Plant Performance Helps Win Coveted Award

Award Winning Sewage Treatment Plant, Paxton, Nebraska. Installation contains one 14' combination Aerator-Clarifier unit. Plant capacity: 75,000 G.P.D., treating domestic sewage. Consulting Engineer: Ogallala Engineering Company. Constructed by Beal Construction Company.

Activated sludge 'Pakage' sewage treatment plants are specifically designed for small communities such as Paxton, Nebraska. They are not large plants scaled down.

The automatic features of the 14' aerator and clarifier in the 'Pakage' plant at Paxton assure trouble-free performance while treating 75,000 G.P.D. of domestic sewage. 'Pakage' plants handle sewage flows from 15,000 to 500,000 G.P.D. in single or multiple units. The plant at Paxton is located near dwellings, like so many other Chicago 'Pakage' Plants, since they are clean, sanitary, and have no objectionable odors. Visitors are amazed at the crystal-clear effluent. In the past 21 years, Chicago 'Pakage' Plants have given trouble-free sewage treatment in over 230 installations.

For small communities, industrial plants and institutions, specify Chicago 'Pakage' Plants. Write Dept. K for complete engineering data and drawings.

* A trade mark of Chicago Pump Co.

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The various well established causes, with a few being somewhat theoretical, are given below. Both types of clogging are listed in the approximate order of incidence. The order of listing has no significance as to degree or seriousness of clogging, however.

Air Side Sources

1. Dust, pollen or smoke particles in air supply.
2. Rust and/or other oxidized or foreign particles picked up in air supply system following filtration. Generally this is air piping scale, but there are other contributory sources as suggested.
3. Oil in air supply from filters or internally lubricated (reciprocating) compressors.
4. Sewage solids resulting from leaks into the air system when air supply is interrupted.
5. Condensation of moisture from air supply, especially during periods of high humidity. While this does not cause diffuser clogging in the true sense, the effect of increasing air pressure loss when water enters diffuser pores is the same. It is not noticeable with clean, new diffusers but may be 10 per cent or possibly more when clogging from some other source is existent. Tests in The Carborundum Co. laboratories on 20 grade plates clogged principally as per source 1. below, showed an 8 per cent pressure loss increase (at 4 cfm. per sq. ft.) with air ranging from 20 to 90 per cent relative humidity.

Liquid Side Sources

1. Finely divided inorganic solids (silt) and sludge solids which enter the porous diffuser structure when air supply is interrupted.
2. Precipitated coating; principally iron salts from industrial wastes and carbonates where water supply is hard.
3. Organic growth or fungi.
4. Grease.
5. Miscellaneous debris during periods when diffusers are exposed in empty tanks.

It is apparent upon reviewing this double list that an astronomical number of different combinations of causes of clogging is possible. Some combination is decidedly the normal case in practice. It is no more likely that two installations of air diffusers will have identical operating conditions with the same combined possible sources of clogging than it is that any two analyses of sewage and industrial waste will be similar. Consequently it is evident that each plant must develop its own best schedule and method of diffuser maintenance and cleaning, if it becomes necessary.

Diffuser Design and Specification

Recognition of the maintenance problem and efforts to minimize it have resulted in two basic advances in diffuser design: (1) The use of stationary plate or tube holders that permit simple removal of diffusers following tank dewatering and (2) the use of completely removable diffuser units (usually tube assemblies of which Fig. 2 illustrates the first example) without tank dewatering. Selection of either design is based on overall economic factors, which often favor completely removable diffusers because servicing can be accomplished on a unit progression basis during operation thereby avoiding standby aeration capacity, over-loading or by-passing.

A more important advance has been in the selection of higher permeability (grade) diffusers, with correspondingly larger pore size. It was presumed originally that small pore diffusers were essential to the release of minimum size air bubbles; hence, maximum efficiency of oxygenation therefrom. Periodic work by A. J. Beck of The Sanitary District of Chicago throughout the past twenty years has established that there is little increase in bubble size between grade 20 and grade 80 diffuser plates. This is due to the fact that in a body of sewage etc. having a relatively low horizontal velocity component, bubbles must attain a diameter of approximately 0.1 in. before buoyancy overcomes surface tension and they are released.* The negligible difference in bubble size, as established by photographs, is sustained by the fact that dissolved oxygen in tanks aerated by small pore diffusers is the same as in tanks aerated by coarser grades.

The above phenomenon is fortunate because the prime justification of large pore diffusers is the critical fact that they are not so effective in intercepting minute foreign particles from the air supply as small pore diffusers; hence, they are not as susceptible to clogging on the air side. Of some added economic importance is that initial pressure loss through the larger pore diffusers is lower and that they probably respond better to cleaning methods.

Figure 3 provides a close approximation of the relation between average pore size of diffusers and grade of standard ceramically bonded aluminum oxide diffusers manufactured by The Carmorundum Co. Since the grade is based on permeability of 1 in. thick material (the standard for plates), it is apparent that thinner wall standard tubes will have a higher permeability for the same grade and pore size. Because of this fact it is recommended that all diffusers be specified on the basis of "grade" in order to obtain the desired pore size.

Grade 40 diffusers generally are recommended where air supply can be maintained in a clean condititon. Grade 60 or grade 80 are suitable where air cannot be filtered satisfactorily but good initial air distribution may be more difficult with these low pressure loss units. Orifice control can be added to assure uniformity although equalization of pressure loss throughout a system normally is obtainable with branch air line valves.

To a considerable extent, the foregoing DESIGN requirements, in addition to those listed under INSTALLATION and OPERATION to follow, are premised on the discussion of each subject in the Air Diffusion Manual to be published by the Federation of Sewage and Industrial Wastes Associations. It is beyond the scope of this outline to give further specifications. They will be covered in greater detail in the Manual.

Diffuser Installation

To prevent as much clogging as possible from the sources as outlined, minimize maintenance expense and generally insure maximum efficiency of air diffusers, there are several somewhat obvious requirements of initial installation as follows:

1. The type of air filter equipment selected and its capacity must be such as to provide a supply that will not contain more than 1.0 mg. of foreign particles per 1000 cu. ft. under the worst anticipated atmospheric conditions. A concentration of 0.5 mg. per 1000 cu. ft. is the standard recommended for average conditions. Double air filtration frequently is necessary for this quality.
2. Air mains and branch air piping should be of such a material and so protected that there will be no scaling or other deterioration that will result in serious clogging of diffusers from the air side. For the same reason, all air lines must be thoroughly clean before operation commences.
3. The blower equipment selected must be of the type that will not contaminate the air supply with its lubricating oil or other foreign material.
4. All diffusers controlled by any given valve should have the same permeability rating within one (1) percent.† All diffusers on the same system should be installed level and to the same elevation within 0.05 ft. Those tributary to each

* A high liquid velocity across the surface of diffusers would tend to "wipe" air bubbles therefrom as they are formed. Under such conditions the small pore diffusers theoretically would provide more efficient oxygenation.

† Where orifice control is included with individual diffuser tube units this close control is unnecessary but it normally is possible on a given shipment of standard tested tubes.

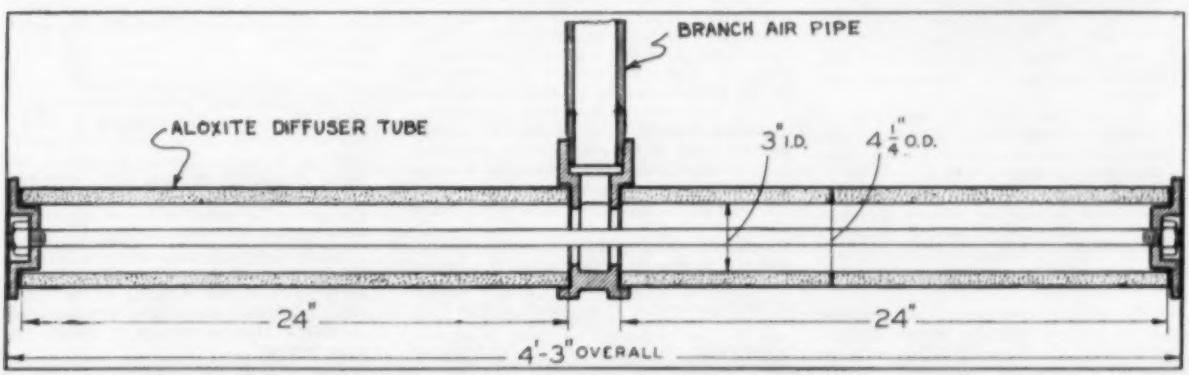

Fig. 2. STANDARD diffuser tube assembly—Link-Belt Co.

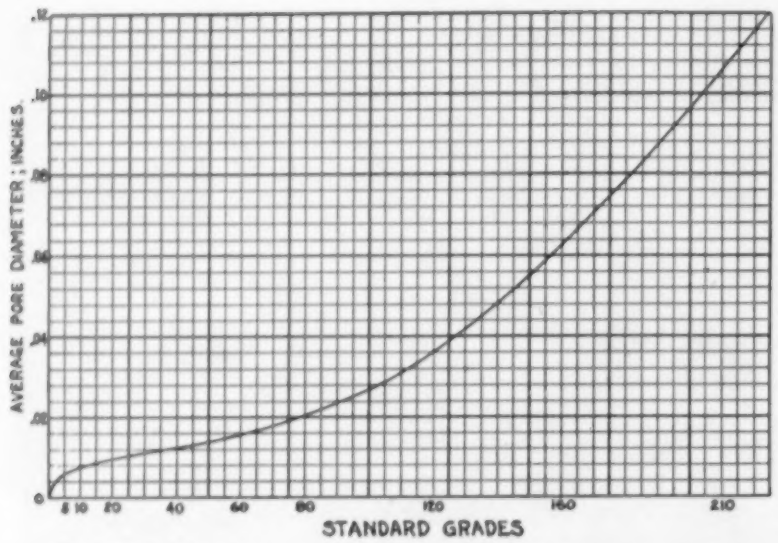

Fig. 3. RELATION between average pore size and grade of aloxite porous media

valve should be at the same elevation within 0.02 ft.

5. The entire aerator system should be initially tested for leaks with clean water above diffusers in order to prevent sludge solids from entering the air system during possible subsequent shutdowns. The system should then be protected until actual operation commences when the air must be discharging before liquor is introduced.

6. The general plant construction, source of blower power, aeration accessories etc. must be such that air supply shutdowns will be non-existent except as a result of unavoidable accident, catastrophic storm or similar occurrence.

Diffuser Operation

An aeration system must be operated in accordance with certain well established practices to keep maintenance cost and diffuser clogging at a minimum, thus requiring low blower pressure and producing generally high efficiency. The various factors involved as listed below are of perhaps even greater importance than those comprising the requirements for proper INSTALLATION.

1. A continuous air supply is the basic operating requirement for prevention of clogging of diffusers from the liquor side. In addition to installation requirement No. 6 described above, it is apparent that thorough blower and motor or engine maintenance, e.g., lubrication, is absolutely essential to avoid shutdowns.

2. Air filters must be constantly and properly maintained to prevent air side clogging.

3. Regular and thorough inspection of the diffuser system is essential to prompt location of leaks or non-uniformity, thus avoiding more serious difficulty.

4. Complete and continuous records of all aeration factors, e.g., blower pressure, likewise is essential to prompt discovery of any condition that ultimately may contribute to a decrease of diffuser permeability.

5. Control or prevention‡ of clogging due to organic growths within diffuser media near the liquid interface may be effected by periodic applications of chlorine gas with air supply.

Methods of Diffuser Servicing or Cleaning

While the theme of this outline of diffuser maintenance thus far has been prevention of clogging, the eventual necessity of permeability restoration through some degree of cleaning must be recognized as a strong possibility. If unavoidable conditions make the problem serious, a thorough analysis of the various known methods is justified. A regular schedule of servicing is then desirable, based on use of the most successful method that is economically justified and within the budget.

Two general procedures of cleaning have developed in keeping with diffuser design development: (1) for diffuser plates more or less permanently cemented into plate holders and (2) for diffuser plates or tubes that are easily removed from stationary or suspended type assemblies. These procedures can be broken down into methods used for liquid side clogging and those used for air side clogging. Rather than attempt a further classification based on methods used for different kinds of diffuser clogging, the established effectiveness of removing various kinds of clogging will be listed with each method.

Because of the practical certainty that any serious clogging is from a combination of sources, it is quite possible that a combination of cleaning methods will be required. For example, the left-hand Fig. 4 photomicrograph of a thin section cut from a 40 grade diffuser plate as taken from actual service, gives evidence of three sources of clogging. The areas marked "*A*" appear to be silt particles embedded in a precipitated coating that contains some iron. The darker areas marked "B" are chiefly the natural ceramic bond of the plate but the extended rough edges plus other minute dark spots indicate dust or some oxide particles from the air supply. The contrast with the right hand photomicrograph of a clean new plate of the same grade is quite apparent.

A. Cleaning Plates in Place—Liquid Side

1. ACID TREATMENT has been used the most widely with different acids of variable strength and a variety of techniques or modifications. A concentrated solution containing 80 per cent sulphuric, 2 per cent sodium dichromate and 18 per cent water appears to be the most effective on serious clogging. Lower strength solutions, and also hydrochloric and nitric acids, should be tried because of cost factor.

The general technique is as follows: Clean plates by water hosing with air on; apply acid to center of each plate using approximately 150 ml. per plate; spread over surface with squeegee; allow to stand for a day or two; blow out with air. More or less acid may be applied depending on plate condition or the operation may be repeated before drying.

Variations of this technique and solution will be found effective for each situation and type of clogging. The method has been used for removal of organic solids, various precipitated coatings and growths from the top of plates.

2. CAUSTIC TREATMENT has been used infrequently with indifferent results but conditions may warrant trial. One method used is to clean plates as described above and leave plates with a small amount of water on the surface: Dissolve 0.1 lb lye crystals over each plate; shut off air; allow solution to penetrate 10 to 15 minutes; add water; blow out with air.

This method is reported as most effective for removal of organic compounds, grease etc. from plate surface.

3. AMMONIA TREATMENT has not been used frequently but is reported favorably. The method follows: Clean surface of plates by water hosing; include wire brushing if necessary; shut off air leaving plates wet; apply approximately 1 pint of a solution of 50 per cent household ammonia and 50% water to each plate; allow to stand overnight; blow out with air.

Method is applicable primarily to plates clogged with organic growths.

4. DETERGENT—WATER JET TREATMENT is the most recent successful method discovered and involved a combined operation. The detergent solution may be ½ pint of commercial liquid known as Glim mixed with 5 gal. of water and 1 qt. of ammonia. Another commercial liquid known as Nacconol is equally effective. The jetting which follows is considered to be an expulsion action within the saturated plate similar to water hammer.

Plates are washed first in usual manner and thoroughly blown out. About ½ pint alcohol is then poured on each plate as a wetting agent. The detergent solution is then applied until plate is saturated and allowed to soak overnight. The water jet cleaning which follows should be as violent and concentrated as possible. It can be accomplished with a 1 in. fire hose line at full pressure with nozzle reduced to ¼ in. The jet is applied for about 30 seconds to each plate with the air off and then another 30 seconds with the air on, in order to locate spots that were missed by initial jetting.

While extensive experience is lacking on this method it undoubtedly removes all types of organic clogging on the liquid side. Inorganic solids also are loosened so that a high percentage is forced out upon jetting.

This method also should be applicable to the cleaning of suspended diffuser tube

‡ An hypothesis for control or prevention of clogging due to progressive dehydration of solids or precipitation of salts, carbonates, etc. near the liquid interface has been proposed by R. C. French of the Department of Public Works of New York City. The proposal is to maintain the air supply near the point of moisture saturation. In addition to supposition that wet air will prevent drying of solids is the suggestion that it will neutralize minute charges that could otherwise develop a minor electroplating action.

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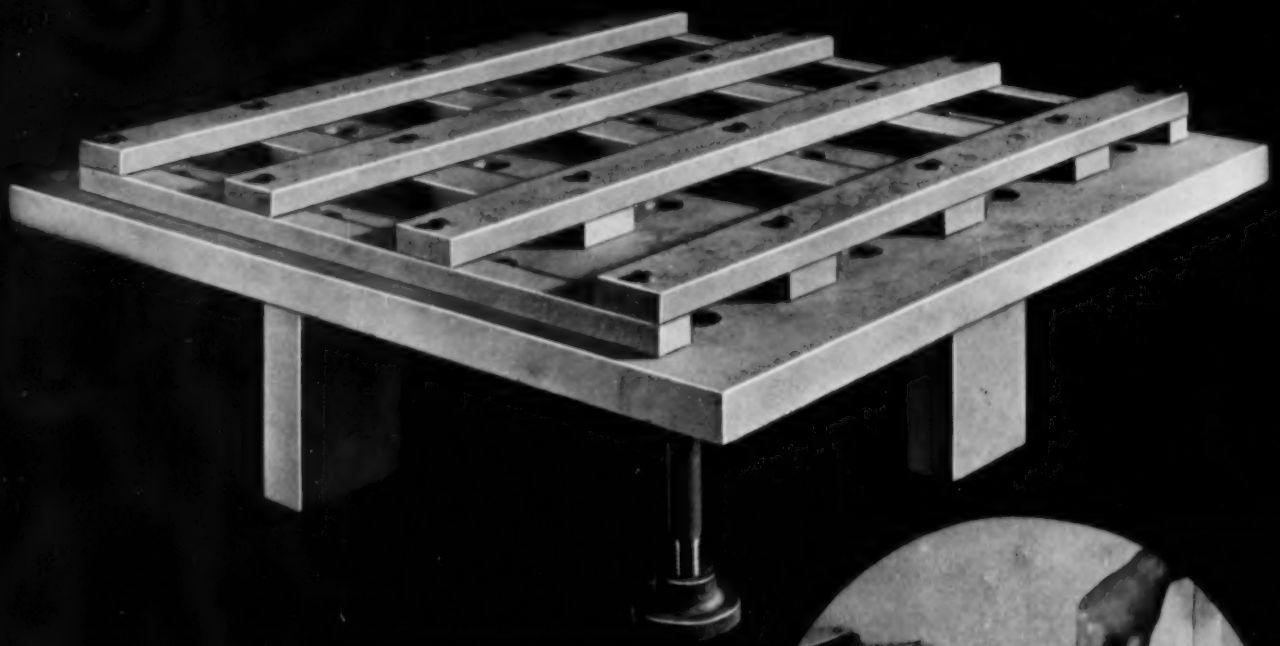

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The new filter bottom manufactured by the Filtration Equipment Corporation offers superior filter plant performance at less cost. Built of new, strong, materials in a revolutionary design, it has a life expectancy equal to the rest of the filter plant itself. The ease of installation and improvements over traditional filter box design keep labor costs to a minimum. In addition, if filter sand and/or gravel must be removed for cleaning or replacement, this highly practical filter bottom can be easily removed for inspection and quickly relaid.

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MANIFOLDS—Copper, Brass, Flow Control Valves Included.

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**John-Manville Trade Name*

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These tables are shipped assembled. Wiring completed down to the junction box containing the transformer and low voltage indicator transmitter terminal blocks. Piping completed from the inlet manifold through the 4-way valves to the exhaust manifold and from the valves to the bulkhead containing connectors for cylinder piping. Installer connects external piping and wiring to terminals provided. Bronze flange at each end of table for bolting to floor. Table top drilled to meet specifications of customers filter gauge.

MAINTENANCE

The electrical valve position indicators and transmitters are hermetically sealed against dust and moisture.

The 4-way control valves are "panel mounted" and all operating parts may be removed without disturbing pipe connections.

The valves are designed to be disassembled and reassembled in 15 minutes or less.

The tables are designed for complete internal ventilation.

FILTRATION EQUIPMENT CORPORATION

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assemblies in place although there is no report to date of such use. A special "ring" device has been developed by Chicago Pump Co. for uniform circumferential application of water jets. It simply is inserted over the end of each tube and moved manually from end to end.

5. CHLORINE PURGING has been used in relatively few places but with some good results. It is undoubtedly the most simple method known except drying.

With no preparatory step chlorine is taken from cylinders and introduced into the air main at a convenient location; preferably near aeration tanks. The rate of application will vary to meet conditions but a starting point and estimate of requirement is 2 lb. per 100,000 cu. ft. of air delivered. The operation is continued until blower operating pressure is reduced and/or until an adequate supply of air can be delivered to diffusers. This may take from two or three days to as many weeks.

Chlorine treatment is effective in removal of organic solids and growths from the diffuser surface. There is an indication of some help in reducing air side clogging from unknown sources simply as a result of the continuous purging action.

6. SAND BLASTING is effective and reasonably fast on silica type porous diffuser plates but slower, and therefore costlier, on aluminum oxide type plates. Blasting should be done during air discharge to avoid further clogging by removed particles and sand. It is estimated that 1 minute is required per plate to remove ⅛ in. from silica type plates or 1/32 in. from aluminum oxide type plates. Accumulated sand and disintegrated plate material must be thoroughly cleaned out of tank after operation.

It is self-evident that this method will remove all types of top clogging. The extent of the operation depends on the depth of solids penetration.

7. OXYACETYLENE FLAME SPALLING is effective in cleaning the surface of aluminum oxide type plates and is more economical than sand blasting. The best apparatus provides a wide flame as illustrated in Fig. 5. This self-propelled apparatus was developed by Linde Air Products Co.

The cleaning procedure involves preliminary plate washing and then setting a portable track alongside of plate holder as shown. Air is left on and the flame applied with nozzle moving over plates at linear velocity of 3 ft. per min. This removes approximately 1/32 in. from the surface and if clogging is deeper, the operation is repeated. Disintegrated plate material must be thoroughly cleaned out of tank after spalling.

This method is applicable to all liquor side clogging. Since it is costlier than other methods (except sand blasting) it is most practical on severe combined clogging that is not effectively eliminated by other methods.

8. BLOW TORCH SPALLING is effective in cleaning silica type plates but is tedious and costly with increasing labor rates.

The procedure is to wash plates by hosing and scrubbing; dry with air discharge; apply blow torch flame at semi tangent with air on and remove material to required depth. Clean tank thoroughly after spalling.

As in all other methods involving removal of a thin layer of the diffuser material, blow torch spalling is effective on all kinds of liquid side clogging.

9. DRYING is the simplest method of all, involving no expense other than for the air supplied. After draining tank, air is blown through diffusers for two or more hours, finishing with an extra high flushing rate. This is effective only in removing light organic (sludge) solids from the surface of otherwise clean diffuser plates.

10. STEAM PURGING has been used rarely but is reported as effective. Low pressure steam is applied to the air line and simultaneously the surface of plates is brushed vigorously with a stiff brush. Organic clogging and grease are removed with this treatment.

Care should be taken with this method to bring diffusers up to steam temperature rather slowly and to avoid a cooling shock after completion. This precaution is to prevent thermal shock cracking of the ceramic bond of diffusers.

B. Cleaning Plates in Place—Air Side

1. SAND BLASTING has been satisfactory on silica type plates but has not been reported for aluminum oxide type plates. It involves removal of one end plate from each plate holder opposite air inlet and passing a sand blast nozzle under the plates by means of a special "boat" carriage.

The procedure is to dry plates thoroughly; remove end plate; insert boat with nozzle pointed upward 30° from horizontal; pass back and forth 3 times and swing nozzle from side to side enroute; remove and blow out plate holder at high rate with air from blower; clean sand and disintegrated plate particles from tank.

This method is effective in reduction of all types of air side clogging listed.

2. GASOLINE PURGING has only been reported at one plant where it is effective in removing a sudden incidence of oily smoke that cannot be intercepted by the air filters. Aviation gasoline is introduced into the air line at a rate of about 2 gal. per mil. cu. ft. Precautions must be taken to avoid possibility of explosion.

This method should be applicable to removal of grease or oil from other sources.

C. Cleaning Removed Plates and Tubes—Clogging on Either or Both Sides

The above heading applies because all of the methods listed below are at least partially effective in removing both liquid and air side clogging and because the simultaneous effect on both sides can hardly be avoided. The particular benefits of each method will be listed as heretofore.

1. ACID AND FLUSHING TREATMENT is perhaps the most widely used and generally successful method of all. While acid pickling *alone* is partially effective and also is used extensively, the water

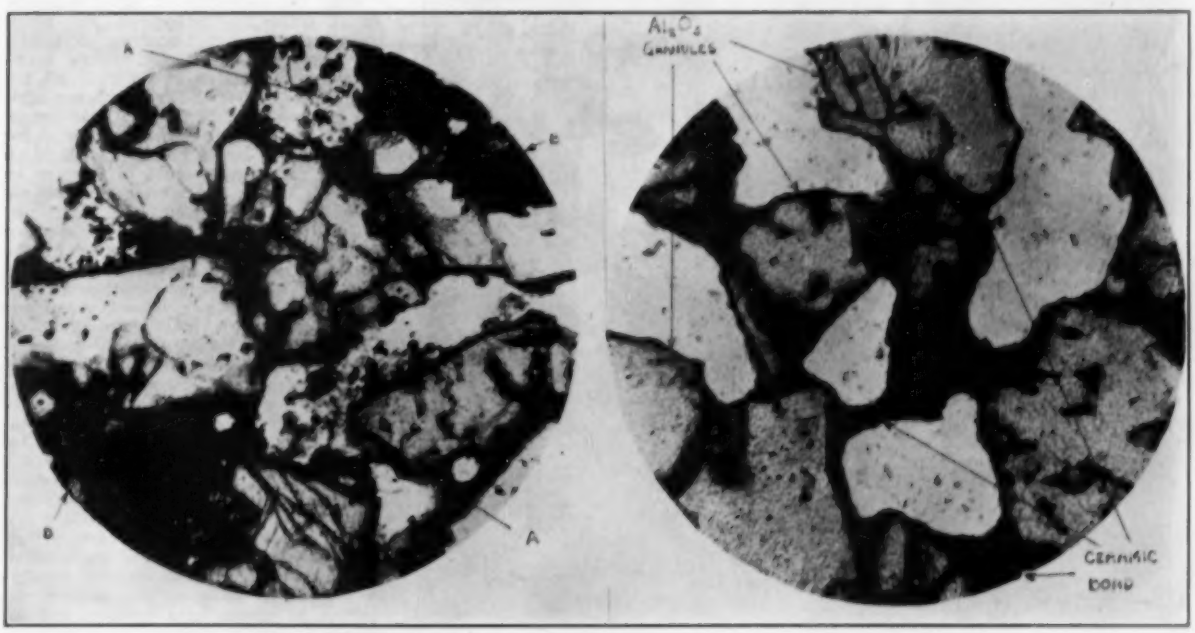

Fig. 4. PHOTO MICROGRAPHS (x50 magnifications) of Grade 40 Diffusers

(clogged plate structure) (clean, new, plate structure)

and air flushing which follows adds much to the result. The second step has been well worth the extra equipment investment in the larger plants where used.

The initial step is to wash diffusers by hosing down in aeration tank; then blow out and dry with air discharge before removal from plate holders or tube assemblies. Submergence in concentrated sulphuric acid (2 per cent sodium dichromate may be added) is the next step, using a large stoneware crock. Diffusers then are placed in a large rubber lined steel soaking tank, similar to Fig. 6 and allowed to soak for as much as 48 hours. This tank is equipped with a drain for removal of spent acid and rinsing water which follows.

Flushing or scrubbing the treated diffusers with water and air is accomplished by clamping in a device similar to that developed at Cleveland's Easterly plant, Fig. 7. (Water and air inlets are connected to the box below plates and are controlled by quick opening valves. Drains are connected to the trough around the outside and a cover provided to prevent initial acid and water spraying.) The flushing time is determined by the operator based on uniformity of air bubble discharge.

This method is most successful in removal of organic solids and precipitates from the liquor side of diffusers. In addition, the flushing action undoubtedly removes some of the loosened undissolved inorganic solids from both sides. The reported diffuser permeability recovery at Cleveland and Chicago (SW) by this method, is from 80 to 90 per cent.

2. Reburning is unquestionably the most thorough method of cleaning known inasmuch as 100 per cent revivification is accomplished. If suitable kilns or furnaces are available, work can be done locally to save transportation. A more complete and satisfactory job probably can be done by the diffuser manufacturer with the type of kiln used for original vitrification.

Diffusers should be washed and dried before shipment for reburning. For ceramically bonded aluminum oxide diffusers, the process is to bring up to the maximum temperature slowly (about 50° C. per hour) and then cool at the same rate. The maximum temperature required for complete permeability restoration will vary with the kind of clogging elements present. Most materials burn out at low temperatures but silt normally is present containing small amounts of Si, Ca, etc. To fuse such elements into the structure and leave open pores, duplication of the maximum original vitrification temperature of approximately 1350° C., is desirable.

It is apparent that this is the most expensive method of cleaning, but it has these advantages: (1) recovery of diffusers equal to new diffusers, regardless of type of clogging; (2) accurately retested (for permeability) diffusers that will insure good initial uniformity of air diffusion upon reinstallation.

3. Caustic Treatment is used infrequently because of limited attack on clogging materials. In some cases, it supplements other methods to advantage.

The treatment consists of placing washed diffusers in a suitable iron vessel and boiling for several hours in a 10 to 15 per cent solution of sodium hydroxide. The time may be from 3 to 8 hours depending on conditions. Boiling in water should follow short treatment to dissolve soap.

Caustic treatment is effective in reducing the clogging from grease and other organic solids. It frequently must be followed by acid treatment to show marked results due to presence of other clogging elements.

Repeated hot caustic treatment over a period of several years should be done with caution because the silica content of the bond is slightly soluble therein. The structure accordingly would be weakened.

4. Detergent—Water Jet Treatment has the principal steps as outlined for cleaning plates in place and can be followed for cleaning of removed plates or tubes. For removed tubes, the Chicago Pump Co. has developed a device for water jetting following detergent soaking. Essentially, it is a ring jet enclosed in a vertical cylinder into which tubes to be cleaned are moved slowly in and out. An additional jet is provided for the inside if necessary. This device was developed primarily for cleaning of "Precision" Saran cord diffuser tubes manufactured by Chicago Pump Co. Tests indicate that it is likewise effective on ceramically bonded aluminum-oxide tubes, often supplied with Swing Diffusers by Chicago Pump Co. where conditions require.

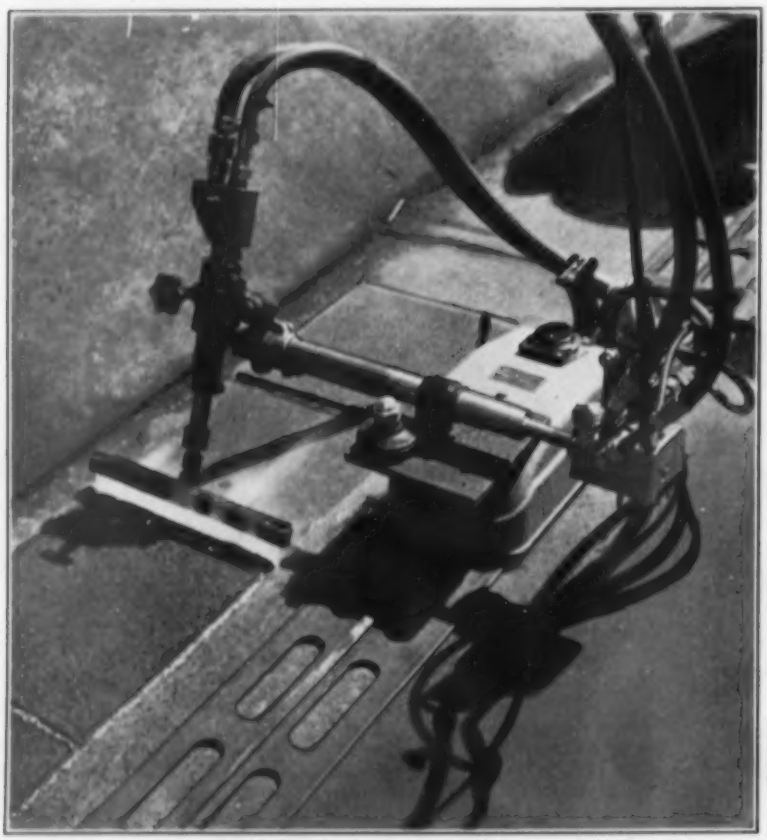

Fig. 5. OXYACETYLENE wide flame spalling equipment
(Linde Air Products Co.)

Economics of Diffuser Maintenance

As stated in the introductory analysis and review of the maintenance problem, the entire basis of its consideration must be that of cost. The elements of plant operation cost are so inter-related, especially within the diffuser system or "heart", that the economics of maintenance are extremely complicated.

It is apparent that diffuser economics is a special and extensive subject in itself. This concluding section, therefore, will merely outline the factors closely related to diffuser cleaning.

With the exception of large activated sludge plants, it is doubtful that many plants keep a separate accurate accounting on: increase of power cost, diffuser maintenance, and replacement sinking fund, for the diffuser system. Such records are critical, however, in establishing a clear picture of this subject. They will enable management to know how far it is possible to go in each direction in order to preserve an economic balance and to establish a realistic budget.

Cost of cleaning by the various methods reported vary extremely because of the variable degree of treatment required in each case, as well as the variation in cleaning method, plant size, labor required and other local factors. It is impossible, therefore, to put a price tag on each method as listed in the foregoing section. Under 1950 conditions, the cost of cleaning would appear to vary from a minimum of perhaps $0.10 per unit for the most simple methods (except drying), up to about $1.75 per unit for reburning.

A somewhat forgotten, yet quite important, factor in this problem of maintenance, is that of diffuser permeability. In the first place, diffusers do not clog uniformly from inlet to outlet of tanks. The permeability, therefore, will decrease and the pressure loss will increase by variable amounts, resulting in non-uniform aeration and decrease in over-all efficiency.

When it comes to cleaning, it is obvious that all diffuser units will not respond

Fig. 6. SOAKING and draining tank for acid treatment

Fig. 7. DIFFUSER plate flushing equipment

(Both at Cleveland Easterly Plant)

uniformly to treatment so that considerable variation from original permeability ratings will result. Without retesting and subsequent reinstallation in accordance with specification No. 3 under INSTALLATION, a tank equipped with cleaned diffuser units would resume operation with some non-uniformity. There is an automatic tendency towards correction of initial non-uniformity, but it is believed that equalization takes place at a slightly higher pressure than may be necessary.

Most of the large activated sludge plants are equipped with diffuser permeability test apparatus. Where smaller plants find it essential to adopt regular cleaning, the installation of simple testing equipment will be found profitable.

Summarizing this phase of the subject, one can only return to the original theme, expressed by one word: *prevention*. Observation and practice of the factors of prevention as outlined herein will pay large dividends.

Acknowledgment

The data and information compiled in this outline are the result of several years' accumulated notes based on reports, personal contacts and correspondence with many sewage works engineers who have a vital interest in the subject. The author wishes to express appreciation to all who have cooperated so kindly. It is desired to acknowledge assistance from the Tentative Manual on Air Diffusion as produced by the entire committee of the Federation and from the following persons in particular:

N. E. Anderson, Chairman, Sub-Committee on Air Diffusion, F.S. & I.W.A.

A. J. Beck, Member, Sub-Committee on Air Diffusion, F.S. & I.W.A.

G. P. Edwards, Member, Sub-Committee on Air Diffusion, F.S. & I.W.A.

J. J. Wirts, Supt., Easterly Sewage Tr. Works, Cleveland, O.

W. A. O'Leary, Chief, Sewage Disposal Design, New York City, D.P.W.

W. Torpey, Engineer, Sewage Plant Operation, New York City, D.P.W.

R. C. French, Engineer, Sewage Plant Operation, New York City, D.P.W.

Miles Lamb, Mgr., Eng. Dept., Chicago Pump Co., Chicago, Ill.

Technical Staff, H. C. Martin, Director, The Carborundum Co., Niagara Falls, N. Y.

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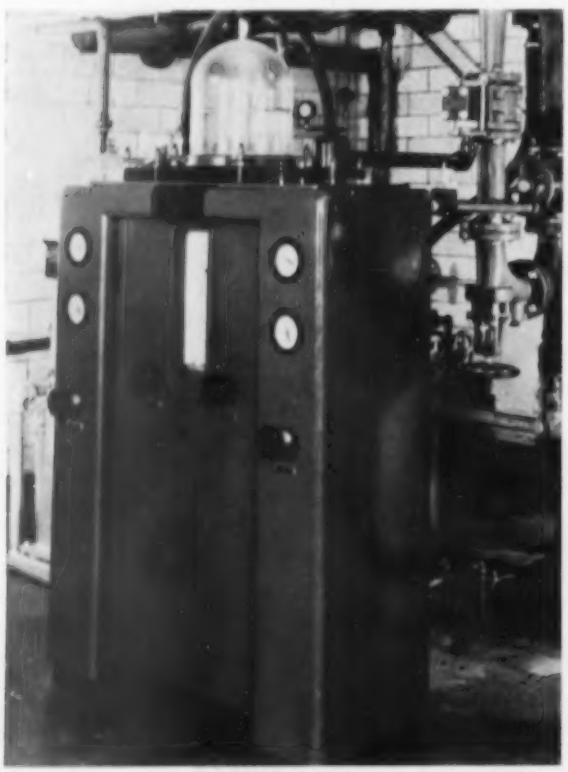
DISINFECTION OF SEWAGE

The need for sewage disinfection cannot today be overlooked. With increasing population the growing demands on water supplies necessitate using sources of supply hitherto considered unsuitable. The increasing popularity of swimming has led to the use of the most available bathing beaches, lakes and water courses. The national resentment against the pollution of streams and rivers is gaining momentum. All of these have centered the attention of sanitarians on sewage treatment. As a final measure of securing complete health protection, sewage disinfection, with chlorine, is accepted practice.



Typical Installation of a W & T High Capacity Chlorinator Installed in a Sewage Treatment Plant.

ODOR CONTROL

The control of obnoxious odors from sewage treatment works, long outfall sewers and other disposal plant appurtenances is distinctly a field for chlorination. Neutralization of hydrogen sulfide (the gas responsible for these obnoxious odors), or prevention of its formation by controlled application of chlorine, is not only quite practicable but also results in economy of operation due to reduction of deterioration in interceptors and allied appurtenances.

B.O.D. REDUCTION

Treatment plants discharging effluents into water courses having extreme seasonal variation in flow have profited from controlled chlorination to reduce biochemical oxygen demand. Field tests have often shown a reduction in the five day B.O.D. of up to 30 per cent.

OTHER ADVANTAGES

Similarly, chlorine prevents filter "ponding." It is also widely used to prevent sludge "bulking." Where grease is a problem, chlorine will aid in its removal and minimize its accumulation in small pipes and spray heads. When added to return supernatant liquor from digesters, chlorine tends to counteract the impact of highly putrefactive liquids from fresh sewage. The thickening of sludge may be greatly benefited by the maintenance of a "chlorine blanket" in the supernatant above the sludge. Chlorine is also useful in the preparation of coagulants such as "chlorinated copperas." Difficult trade wastes, such as those containing cyanides, can be effectively purified by designing means for the application of chlorine into the process.

EQUIPMENT

For every sewage plant, there is W&T Equipment to fit. Visible Vacuum Chlorinators with capacities from ounces to 6000 pounds per day—Solution Feed and Direct Feed Chlorinators for small plants—and Reagent and Chemical Feeders to meet many varied chemical treating applications. All W&T Apparatus is backed by over thirty years' experience and is job-engineered by chlorination specialists.

TECHNICAL INFORMATION

W&T representatives will gladly discuss any sewage chlorination problem. Technical bulletins on the many phases of sewage chlorination and W&T Chlorinators will be sent free on request.

NOTES ON SEWAGE CHLORINATION*

IN SEWAGE treatment, disinfection is practiced to destroy pathogenic bacteria and to reduce the total number of bacteria. Chlorine (sometimes calcium hypochlorite) is the usual disinfecting agent, but chlorine is also used for other purposes in sewage treatment. The containers in which chlorine is purchased and the chlorine feeders used are the same as used for water chlorination.

Purposes of Sewage Chlorination

Disinfection is the most important purpose of chlorination in sewage treatment, principally to prevent nuisance and to protect water supplies, bathing beaches and fishing areas.

Other important uses of chlorination in sewage treatment include: *Putrefaction and odor control* by the use of sub-residual amounts of chlorine to prevent early decomposition of the organic matter or to combine with hydrogen sulfide and other odors already formed.

Reduction of B.O.D. to the extent of approximately 2 ppm for each ppm of chlorine added.

Control of corrosion by reducing the hydrogen sulfide content of sewage.

Grease removal by the addition of chlorine and air.

Improved trickling filter operation from chlorination which reduces odors from the filter, reduces ponding, and controls the growth of filter flies.

Bulking control in activated sludge by adding chlorine to the return sludge in an amount calculated according to the formula:

lb Cl_2 per 24 hr $= 0.0000834 \times$ S.I. $\times$ F $\times$ W, where S.I. is Sludge Index (Mohlman) F is mgd of return sludge and W is ppm of suspended solids in return sludge.

Sludge thickening in the activated sludge process by maintaining a residual of 1 ppm in the supernatant liquor layer of the sludge thickening tank.

Digester foaming control by adding chlorine in sufficient amounts to the raw sewage. The amount required depends on local conditions.

Re-use of sewage effluents is possible only when chlorination for disinfection is practiced.

*These notes were adopted from B-I-F Industries Keep Sheet No. 15 by permission.

Types of Chlorination

Whereas water chlorination may be practiced to produce either a combined or free residual chlorine, sewage chlorination involves the production of a combined residual. In some instances a sub-residual is used. Although the process is really combined chlorination it is usually termed simply, chlorination.

Points of Application

Application points for sewage chlorination include:

Upsewer chlorination where chlorine is added before to sewage before it reaches the treatment plant. This practice is usually for the purpose of keeping the sewage fresh and preventing odors.

Prechlorination is the addition of chlorine at the entrance to the sewage treatment plant or ahead of primary treatment units.

Post-chlorination is the addition of chlorine to sewage after some other treatment process, usually primary or secondary treatment. Chlorine is usually added ahead of a contact tank or final settling tank or final long outfall.

Chlorination Capacity

The amount of chlorine used in a sewage treatment plant is expressed in terms of pounds per day and chlorine feeders are calibrated in units of lb per day. The amount of chlorine required depends on the desired result, the chlorine demand in ppm, the flow in mgd, the amount of residual desired, in ppm and contact time.

Chlorine demand depends on the amount and kinds of chemical substances in sewage which will react with chlorine as well as on time of contact and temperature. Chlorine demand is defined as the difference between the amount of chlorine added and the amount of the residual after a specified time. Residual chlorine is that chlorine which will react with ortho-tolidine.

The amount of chlorine required will vary for different sewages, different times of the day, different days of the week and different seasons. It is usually determined on the basis of a 15 minute contact time, but some states require 20 minutes contact.

One set of standards of design requires a capacity available to produce a residual of 2 ppm after 15 minutes, or enough capacity to dose raw sewage with 25 ppm, or primary effluent with 20 ppm, or trickling filter effluent with 15 ppm or activated sludge effluent with 8 ppm.

Control

The feeder capacity required can be calculated from the required dosage multiplied by the factor 8.34 and by the flow in mgd.

As with chlorine feeders used for water chlorination, the types of control available include manual, semi-automatic (step) programmed control, and automatic proportional control, wherein the equipment adjusts automatically to maintain a preset dosage regardless of the change in flow of sewage. The types of feeders available are the same as those described under water chlorination.

Installation

Chlorine feeders for sewage chlorination should be installed according to certain principles. The point of application should produce quick and thorough mixing and sufficient contact time for the treatment desired. The equipment must be accessible to the operator both for normal operation and for maintenance. The space allowed for the chlorine feeders must be sufficient to allow storage of containers and ease of operation and control. Safety factors must be given full consideration in any chlorine feeder installation.

Operation

Inasmuch as the chlorine demand of a sewage changes markedly throughout the day, it is highly desirable to control the dosage rate accordingly or chlorine added may be wasted, either as an excess or as an insufficient amount to produce the desired disinfection. Where laboratory facilities are available, frequent determinations of chlorine demand and concurrent changes in chlorine dosage rates should be made. Many plants make a study of the chlorine demand curve and determine a pattern of dosage rates. The minimum number of changes made in dosage rates should be three a day. Changes every hour or every two hours is more productive of efficient chlorination. Programmed control is highly effective for this purpose.

Chlorination Control Nomogram*

THIS NOMOGRAM for chlorination control has been developed primarily to aid in determining the proper setting of chlorine gas feeders for use in the treatment of water, sewage and industrial wastes, and control of slime in cooling, process and white water systems. However, most dry and liquid chemical feed calculations involve consideration of the same factors applicable to chlorine feed, hence, it is apparent the nomogram has broad use and application.

Directions for use of the nomogram are given on the other side of this Keep Sheet. Attention is called to the fact that this "multiple" nomogram is applicable to all conditions, if the user properly employs the factors of 10, 100, 1000, etc., where necessary, and properly places the decimal point when the calculation is completed.

Applications

1. Design Work

For determining the maximum capacity of chlorination equipment needed—If the chlorine requirement of the liquid to be treated is known (or if some value is set as maximum requirement in ppm by a governmental agency), and if the maximum expected flow is known or can be estimated, the nomogram affords a simple means of determining maximum feed rate required.

2. In Operation and Control

As an aid in setting chlorine feed rates in water and sewage chlorinating stations — Having established by chemical tests the chlorine dosage required to effect a desired residual, the nomogram may be employed to determine the proper chlorine feeder setting to produce that residual at any given flow rate.

3. In Plant Performance

To accurately and quickly convert accumulated "known" data into average performance and to readily transpose momentary feed and flow rates to dosage in ppm—From the flow measuring device, accumulated flows over a selected period or momentary flow may be determined. Chlorine flow totalizers or loss in weight measurements of containers on scales provide accumulated feed information and chlorine recorders or the chlorine feeder indicates momentary feed rate in lb per 24 hr. With these data applied to Lines C and A, the chlorine dosage in ppm may be read on Line B.

Examples of Use

1. *Direct Reading*—For a flow of 0.8 mgd (556 gpm) with a chlorine requirement of 1.1 ppm, place straight-edge on 0.8 on Line A and on 1.1 on Line B. (Note that angle with Line B is approximately a right angle and therefore is satisfactory). Read value of 7.35 on Line C. Setting for chlorine feeder is 7.35 lb per 24 hr.

2. *Single Multiplier*—Where the straight-edge nearly parallels Line B—For a flow of 0.2 mgd (139 gpm) with a chlorine requirement of 0.1 ppm, place straight-edge on 0.2 on Line A and on 0.1 on Line B. Note that the angle of the straight-edge with Line B is far from a right angle. Therefore, for more accurate results, place straight-edge on 0.2 on Line A and on 1.0 on Line B and read value of 1.67 on Line C. Multiply this value by 0.1. Setting for chlorine feeder is .167 lb per 24 hr.

3. *Single Multiplier*—Where straight-edge does not cross Line C.—For a flow of 0.7 mgd with a chlorine requirement of 2.5 ppm, note that the straight-edge does not cross Line C. Therefore place straight-edge on 0.7 on Line A and on 0.25 on Line B. Read value of 1.45 on Line C. Multiply this value by 10. Setting for chlorine feeder is 14.5 lb per 24 hr.

Note: Straight-edge approaches right angle with Line B for this placement and is therefore more accurate than using 0.07 on Line A and 2.5 on Line B, which would give the same value on Line C at 1.45.

4. *Single Multiplier* — For normal placement of straight-edge.—For a flow of 7.0 mgd with a chlorine requirement of 0.6 ppm, place straight-edge on 0.7 on Line A and on 0.6 on Line B. Read value of 3.5 on Line C. Multiply this value by factor of 10. (Factor of 10 introduced on Line A.) Setting for chlorine feeder is 35 lb per 24 hr.

The procedure would be the same for a flow of 70 mgd or 700 mgd, etc., using multiplier factors of 100, 1000, etc.

5. *Double Multipliers*—For conditions where factors are introduced in both Lines A and B.—For a flow of 1.7 mgd with a chlorine requirement of 8.0 ppm, place straight-edge on 0.17 on Line A and on 0.8 on Line B. (Note, if straight-edge were placed on 8.0 on Line B, it would not cross Line C.) Read value of 1.13 on Line C. Multiply this value by 100 (factor of 10 on Line A times factor of 10 on Line B.) Setting for chlorine feeder is 113 lb per 24 hr.

The same procedure would be followed for a flow of 17 mgd with a chlorine requirement of 13 ppm, in which case the straight-edge would be placed on 0.17 on Line A and on 1.3 on Line B. The value on Line C of 1.84 would then be multiplied by 1000 (factor of 100 on Line A times factor of 10 on Line B).

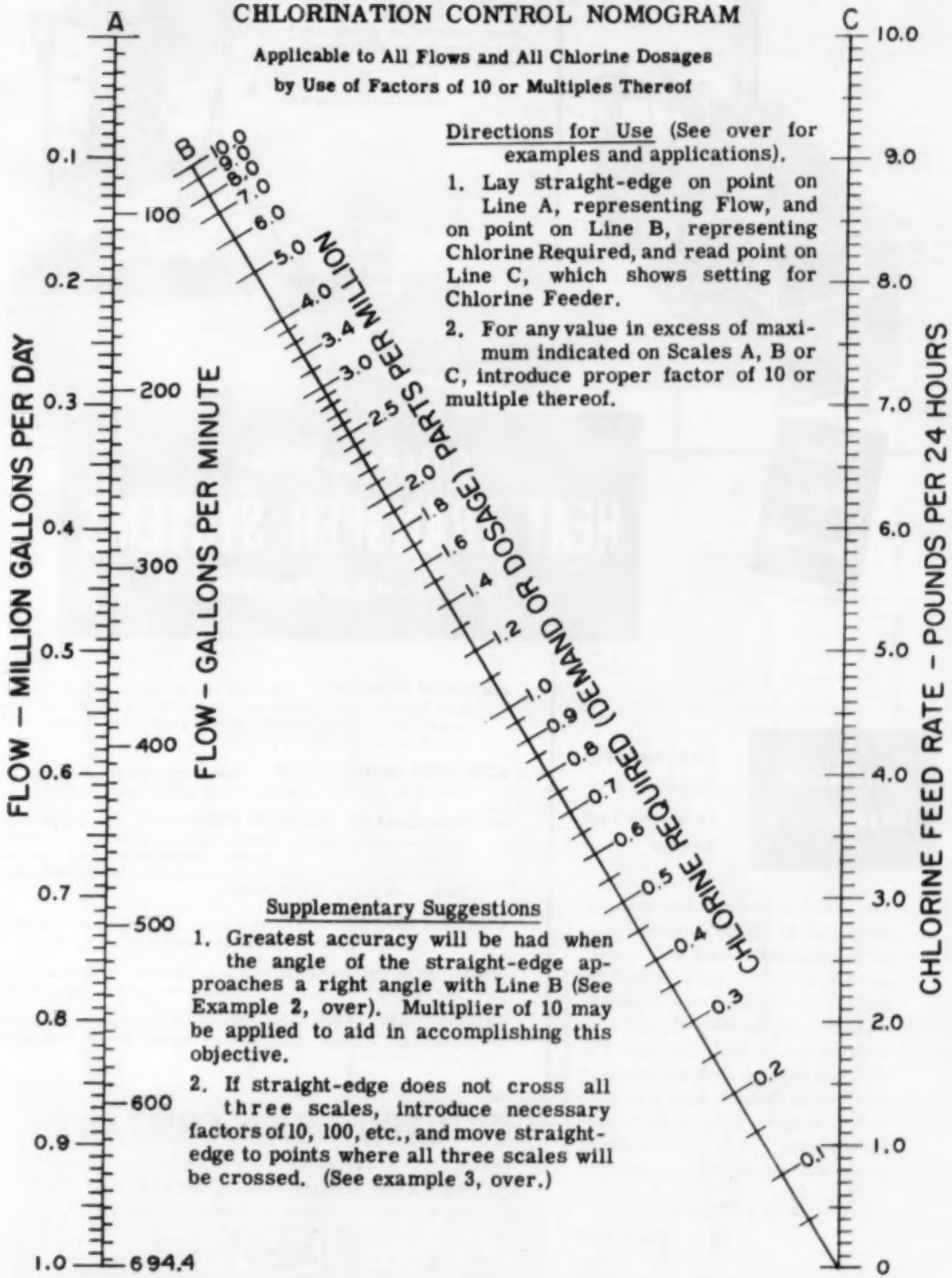
6. *Determination of Dosage*—From recorded flow rate and chlorine feed rate—For a flow of 0.63 mgd and a chlorine feed rate of 5.8 lb per 24 hr, place the straight-edge on 0.63 on Line A and on 5.8 on Line C. Read value of 1.1 on Line B. Chlorine dosage is 1.1 ppm.

This operation may also be used for values of flow and chlorine used, greater than the values on Lines A and C, by introducing the proper factors of 10, 100, etc.

*Reprinted from Keep Sheet No. 21, of B-I-F Industries, Inc., by permission.

CHLORINATION CONTROL NOMOGRAM

Applicable to All Flows and All Chlorine Dosages by Use of Factors of 10 or Multiples Thereof

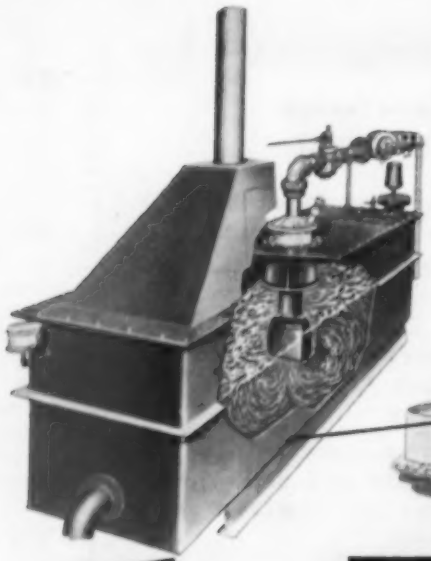


Directions for Use (See over for examples and applications).

1. Lay straight-edge on point on Line A, representing Flow, and on point on Line B, representing Chlorine Required, and read point on Line C, which shows setting for Chlorine Feeder.
2. For any value in excess of maximum indicated on Scales A, B or C, introduce proper factor of 10 or multiple thereof.

Supplementary Suggestions

1. Greatest accuracy will be had when the angle of the straight-edge approaches a right angle with Line B (See Example 2, over). Multiplier of 10 may be applied to aid in accomplishing this objective.
2. If straight-edge does not cross all three scales, introduce necessary factors of 10, 100, etc., and move straight-edge to points where all three scales will be crossed. (See example 3, over.)



The Chicago Selas system may be mounted on top of the digester to cut installation costs. Cut-away shows simplicity of system with only diffuser for hot gases extending into the sludge.

Compact Control Panel for the Chicago-Selas Sludge Heater.

CHICAGO SEWAGE EQUIPMENT

Chicago-Selas
HEAT TRANSFER SYSTEMS
for Sludge-Heating

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Two Experts Teamed Up to Serve You Better

The principle of direct heat transfer, developed by the Selas Corporation of America, has found wide acceptance in industrial applications. Together with Chicago Pump Engineers, this principle has been applied with great success to sludge heating. The efficiency and operating advantages of this form of sludge heating have been well demonstrated, first at the City of Philadelphia and at other treatment plants throughout the country.

Write to Dept. G.

MAXIMUM EFFICIENCY — One pass through the small heat transfer tank boosts sludge temperature 10 to 20 degrees F. Approximately 90% of heat available in the digester gas is transferred directly to the sludge.

LOW COST INSTALLATION — Heater and transfer tank may be located at digester, requiring minimum piping and valves.

NO HIGH COST OIL STAND-BY EQUIPMENT—Operates efficiently on nationally available manufactured gas if necessary. A single control valve is the only stand-by equipment required. Low gas consumption makes Chicago-Selas system ideal for medium sized plants with limited gas production.

UNIFORM HEATING — Agitating action of heated gases expelled into transfer tank assures complete heating of all sludge.

MINIMUM MAINTENANCE — Heat is distributed without mechanical equipment in the tank. No sludge tubes to cake—no cleaning.

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Swing Diffusers, Stationary Diffusers, Mechanical Aerators, Combination Aerator-Clarifiers, Comminutors.

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SLUDGE DISPOSAL

THAT MATTER which settles from sewage (except grit) is termed sludge. Raw sludge results from primary treatment, secondary sludge comes from final clarifiers.

The two sludges are entirely different in characteristics (and trickling filter humus differs somewhat from activated sludge). Regardless of source, these solids cannot be disposed of without some treatment or nuisance will result. Treatment of sludge may consist of digestion, dewatering and drying and/or incineration. In some instances dewatering, drying and/or incineration take place without digestion. Secondary sludge when dried makes an excellent soil conditioner (or fertilizer); digested sludge is less desirable for this purpose and raw sludge should not be used on the soil.

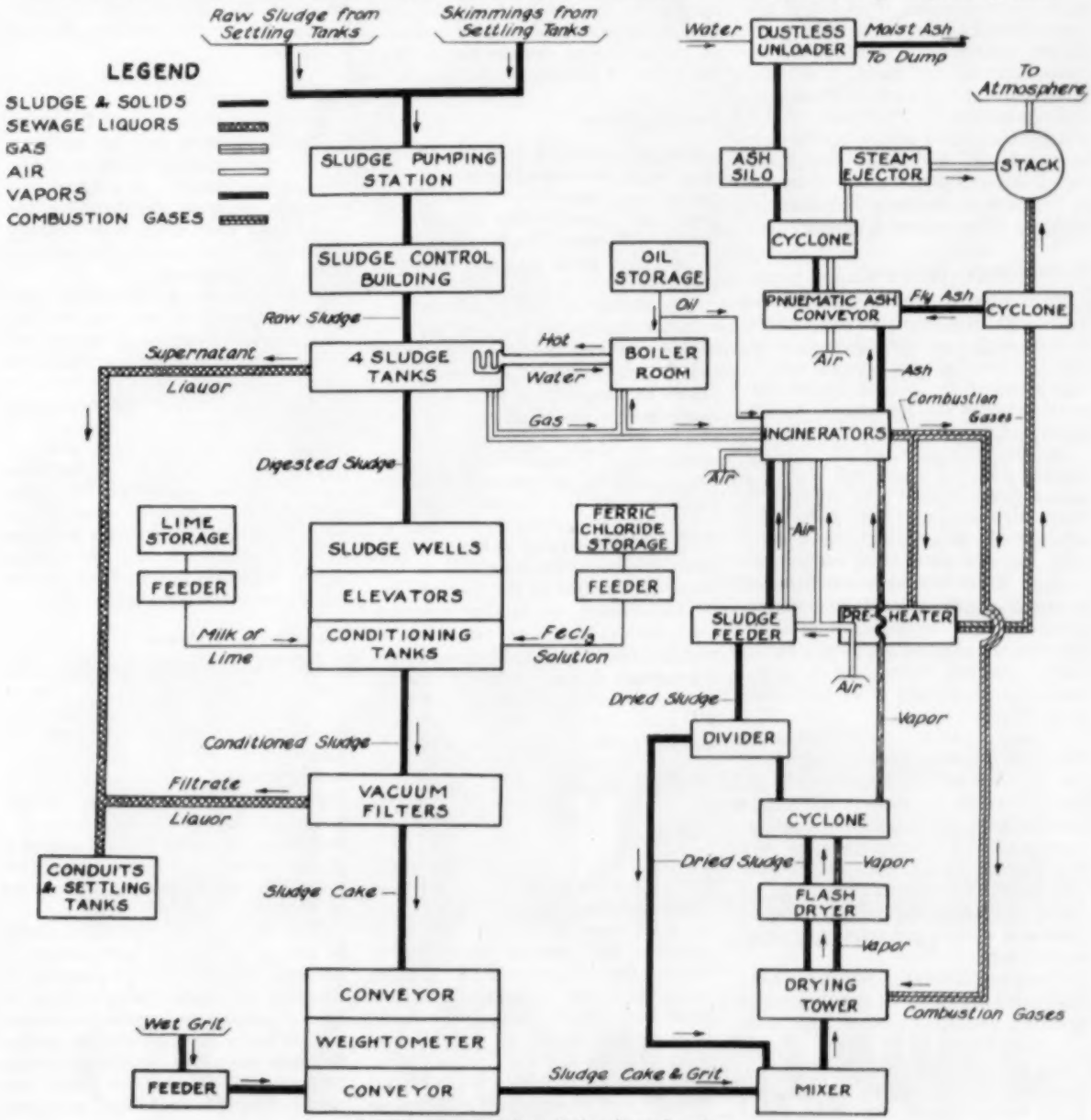
Digestion of sludge is an anaerobic bacterial decomposition, that is, it takes place in the absence of atmospheric oxygen.

Since all sludges contain water, some more than others, one of the methods of sludge treatment is to reduce that water content. Included in the methods of accomplishing this result are the processes of sludge thickening, draining on sand beds, vacuum filtration and biological flotation.

Dewatered sludge may be dried in the open air on sand beds, or mechanically in furnaces designed especially for that use. The former process is termed natural drying.

Where disposal areas and facilities are not available for either wet or dried sludge, it may be burned in an incinerator. The resultant ash must be disposed.

The accompanying diagram shows a modern sludge disposal system.



Flow diagram of modern sludge disposal system

SLUDGE HANDLING*

THE DISPOSAL of sludge is a major problem in a sewage treatment plant. Facilities for handling sludge add to the cost of construction and operation. Problems peculiar to the handling of sludge vary according to the type of sludge being handled.

Raw sludge from primary treatment plants contains from 5 to 8 per cent solids of heterogeneous nature including coarse particles, fibrous material, grease, fine sand, trash and ground screenings (where screenings are comminuted.) Activated sludge and trickling filter sludge is relatively homogeneous, with less than 3 per cent solids and presents few hydraulic or mechanical problems in handling; trickling filter humus is similar.

Screenings and Skimmings

Problems of handling ground screenings can be reduced by using screens with openings of ¼ to 1 in. and discharging the ground screenings ahead of the screens. Coarse material leaving the grinder is caught again and reground.

Skimmings consist of all types of flotable material which will rise in a sedimentation tank. This material is frequently skimmed off to wells from which it is pumped to digesters along with the raw sludge. A major percentage of this heterogeneous material is grease which includes fats, waxes, soap and oils. In addition to these substances, skimmings also contain sticks, matches, leaves, paper, feces, soap, rags, hair, and other miscellaneous objects.

In some plants, skimmings have been sold for their grease content but this practice is not generally economically feasible. In other installations, skimmings are burned in special incinerators. Where skimmings are transferred to digestion tanks with raw sludge, the resulting problems include pumping difficulties, clogged lines and meters and scum formation in digesters.

Pumping difficulties result from the congealed character of the skimmings and their resistance to flow. This problem is overcome to some extent by introducing excess water with the skimmings in the well and ahead of the pump suction. Sludge lines handling skimmings become reduced in size and may even clog entirely due to the deposition of the grease on the inside surface of the lines.

Metering of skimmings is difficult because of the tendency of the material to deposit on the inside surfaces of the measuring devices and to clog the throat of differential producers.

Pumping Sludge

Pumps employed for raw sludge may be positive displacement piston pumps or "screw-feed" centrifugal pumps or a combination grinder and centrifugal pump. Clogless centrifugal pumps have come into use in recent years.

The choice of pump will usually consider factors of location, type of sludge, suction and discharge head, etc. Generally, raw sludge pumps are placed in pumping stations below the water level in the sedimentation tanks and therefore operate under a positive suction head. Provision must be made for a build up of pressure resulting from depositions in the discharge line. Thus rugged equipment is required. It is always desirable to have a minimum length suction pipe and as few bends as possible in the suction line.

Maintenance on sludge pumping equipment is high, wear on packing is rapid. This is especially true where the sewage comes from a combined system and contains fine grit (80 to 100 mesh). Cleanliness is a problem in sludge pumping stations caused by leaking packing, cleaning obstructions from pumps, and drawing samples.

Piping

The sizing of pipe for sludge pump discharge lines presents a problem in sludge handling. Some designers prefer small pipes to produce high scour velocities and prevent deposition in the pipe line; others prefer large pipes which give low velocities with low head loss. These pipe lines should have as few bends as possible and cleanout holes at elbows are desirable.

Where skimmings are pumped through raw sludge lines and deposition of grease occurs, cleaning may be done by steam injection to heat the water in the lines. For cast iron pipe this heating (and cooling) must be slow and controlled to prevent cracking. Temperatures of 150 to 180 deg F are desirable. The use of steel pipe for sludge lines is warranted where steam cleaning is to be used and it has been suggested that twin lines be installed so that interruption to pumping can be avoided during cleaning operations.

Metering

Because of the nature of the material being metered, and the tendency to clog, the metering device should be the simplest possible. A Venturi tube especially designed for handling the sludge and with continuous flushing systems for the pressure connections is the most practical.

Some designers do not include metering devices in sludge lines, first because of the difficulties of keeping the device clean and secondly because the nature of sludge makes it difficult to measure rate of flow. Other designers believe that a measurement of sludge pumping discharge, even if inaccurate, is desirable. It indicates whether or not pumps are operating or plugged, and it gives some indication of the amount of sludge removed in the settling tank and the loading on the digestion tanks. Both factors are important to good operation.

Miscellaneous Problems

Sampling of sludge presents difficulties, yet is essential to control of loadings on digesters as well as determining the effectiveness of sedimentation. In order to control the concentration of sludge discharged to digesters, it is necessary to sample frequently to make sure that the concentration of sludge being pumped is at the desired level. This control prevents the costly pumping of volumes of cold water into digesters.

The handling of secondary sludge is not as difficult as raw sludge; it presents few problems of pumping or clogging of lines. Sampling is required in order to control the amount of free water pumped with the sludge. In some instances, secondary sludge is thickened to reduce its water content before it is discharged to digesters or other disposal processes.

* Material for these notes was obtained from "Problems in Sludge Handling" by C. R. Velzy—*Wat. & Sew. Wks.*, Ref. & Data issue, Apr. 1948.

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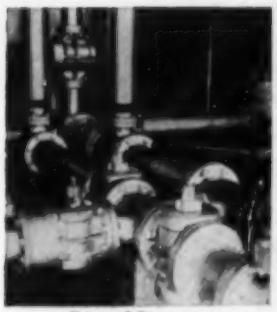

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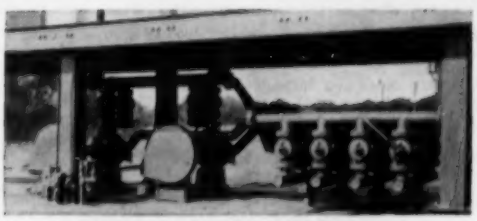

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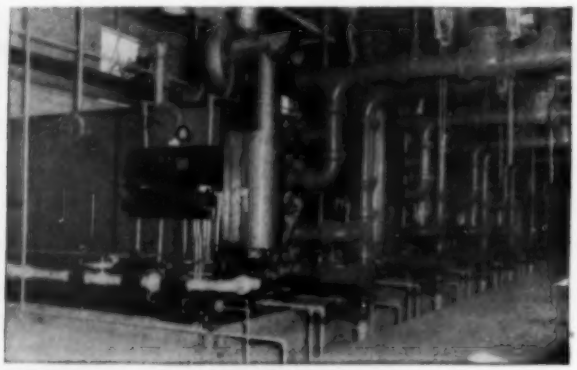

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SLUDGE DIGESTION AND GAS UTILIZATION

RAW SEWAGE sludge is undergoing active decomposition as it settles to the bottom of a primary sedimentation tank. This decomposition can be controlled if the sludge is removed almost immediately to a separate compartment, otherwise the sludge will float upward into the settling zone and leave the settling tank with the effluent.

Sludge Digestion

Fine screenings are practically always incinerated, but raw sludge from primary sedimentation tanks is practically always digested. In many trickling filter and activated sludge plants, the sludge from the final clarifiers is returned to the primary clarifier, or it may be pumped directly to the digesters. The former practice has less upsetting effect on digestion.

The decomposition or digestion of sludge is brought about by bacteria which function in the absence of atmospheric oxygen. These organisms are always present in sewage and begin to develop as soon as conditions become anaerobic (no dissolved oxygen). The principal bacteria are of several types working together, but the reaction involved is an anaerobic hydrolysis and oxidation of the organic matter to produce fatty (organic) acids which in turn are decomposed to produce gas consisting of carbon dioxide and methane and small amounts of hydrogen, hydrogen sulfide, and ammonia which is dissolved in the liquid. Although most of the gas is produced in the first week, further digestion is necessary to stabilize the remaining organic matter, reduce its water binding characteristics, and produce a good digested sludge, which will be black, have a slightly tarry odor, drain well, and be inocuous as fill. Thus there are two stages of digestion.

If digestion tanks are overfed in relation to capacity, or lack sufficient heat, or fail to maintain the proper pH, the acid "intermediates" production may outstrip the conversion of those acids to gas. The tanks then become sour, the pH drops, odors result, gas production decreases, digestion slows down and may stop.

Control of temperature is very important and in some cases the addition of lime has been used to raise the pH which has been lowered by the production of the organic acids. Best control is to reduce the rate of feed and to keep a check on the volatile acids, to make sure that they do not go above 2000 ppm.

Digestion Tanks

Digestion takes place in the sludge compartment of an Imhoff tank or in separate sludge digesters, where clarifiers are used for primary sedimentation. No attempt is made to heat Imhoff tanks, but the sludge compartments are usually well below ground level. Separate sludge digesters are heated (either by internal hot water coils or by external heat exchangers) to maintain approximately optimum temperature.

Generally, digester capacity of 2 to 4 cu ft is provided per capita in heated tanks. More is required in unheated tanks and where ground garbage is a factor in the quantity of sludge received. Digesters of 1 cu ft per capita have been built but scum may result with this low capacity.

Provision is made in all tanks for the addition of raw sludge, and the removal of supernatant liquor and digested sludge, the former from the upper part of the tank and the latter from the bottom of the tank which usually has a conical bottom to facilitate sludge removal.

Supernatant liquor is withdrawn from the digestion tanks when raw sludge is added; intermittent addition in rotation to several tanks is generally practice in preference to continuous addition. Supernatant liquor should be fairly free of suspended matter. It is high in B.O.D. and has a high chlorine demand, both of which vary with the solids carried. It is usually returned to the incoming raw sewage; it may be treated by aeration, elutriation, or settling before return.

Digested sludge is drawn at intervals from the bottom of the tank and transferred to the next step in the process, dewatering. Digestion reduces the amount of sludge solids by 35 to 50 per cent and the volume of sludge by about one-half, while the concentration of solids is practically doubled. Since digestion takes place in two stages (gasification and liquefaction, and dewatering of colloids), it has been found advantageous to separate the two stages into two tanks; i.e., two-stage digestion, with 65 to 75 per cent of the total digestion capacity in the first stage. Usually only the first stage is heated and provided with gas collection. The over-all capacity and cost of construction and operation can be reduced.

Operation Problems

Among the problems of sludge digestion tank operations are (1) mixing raw sludge with undergoing active digestion (i.e., seeding), (2) heating, (3) scum formation, (4) ineffective separation of sludge and supernatant liquor, (5) foaming and (6) fine sand.

The design of modern tanks has been developed to minimize all of these problems. For example, digestion tanks may have fixed or floating covers; each has certain advantages. Floating covers submerge the scum and keep it from drying out and utilize recirculation of supernatant liquor or digested sludge to "knock down" the scum, and maintain good seeding.

Fixed cover digesters may employ mixers in the covers or down draft mixing tubes in the center of the tanks to provide mixing of seed and raw sludge and to minimize scum formation. Heating is accomplished by coils around the tanks or by external heat exchangers which provide heating and thorough mixing of seed and raw sludge and reduce scum.

The latest method for controlling scum formation is the recycling of gas from the digester into the area of the scum layer (the PFT-Pearth System) or into the sludge compartment (The Chicago Pump Co. Catalytic Reduction Process).

Where poor supernatant liquor exists because of lack of separation of sludge and liquor, the cause is usually due to high loadings of solids per unit capacity and to high gas production rates per sq ft of surface area in the tank. Special devices, essentially screens, are available to aid in assuring that the best supernatant liquor will be selected for withdrawal.

Foaming is a condition which results when digestion proceeds at rates above normal for the particular tank. This condition occurs when tanks are overloaded, or when tanks are overfed at low temperatures and then warmed up to normal operating temperatures. Overloading often will produce an excess of volatile acids which depress the pH to a point where digestion practically ceases. This is sometimes termed a "stuck" digester. Remedies consist of discontinuing feeding or

NOW CRP* DIGESTION gives 3 to 7 times the capacity from the same digestion tank

CATALYTIC REDUCTION PROCESS* Triples Sludge Digestion Rate to Boost Digestion Tank Capacity

The CATALYTIC REDUCTION PROCESS is the only proved process for accelerating biological digestion. Originating in 1946, the PROCESS was developed, tested and verified over six years on both laboratory and plant scale. The results have been proven in full scale plant operation at the Columbus, Ohio and Erie, Pennsylvania Sewage Treatment Plants. The PROCESS is now being installed in seven other cities.

DETAILS OF ONE TEST

The CATALYTIC REDUCTION PROCESS applied to one 70′ tank at the Columbus Plant digested 3.38 times the quantity of sludge solids digested in a similar tank in parallel operation not using the PROCESS. The tank operating under the PROCESS produced a reduction of solids within established ranges, normal gas production and readily driable odorless sludge.

PREVENTS FLOATING DIGESTIBLE SOLIDS

By providing accelerated digestion, the CATALYTIC REDUCTION PROCESS offers the only fundamental and satisfactory method for preventing deep surface accumulation (sometimes mistakenly called scum) of digestible solids that are symptomatic of inadequate digestion. CRP simultaneously accelerates the uniform digestion of ALL digestible solids.

Reports Available

Reports describing the PROCESS in detail are available on request. Write to Department F.

** Patents Applied For*

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Flush Kleen, Barn-Feller, Plunger Horizontal and Vertical Non-Clogs Water Seal Pumping Units, Samplers.

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Eight 110-ft. diameter Chicago-Wiggins Lodek Covers at the City of Philadelphia Southwest Disposal Plant.

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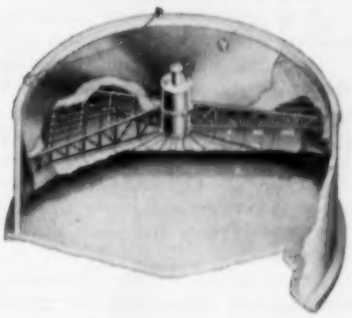
Ask leading engineers why, in the past four years, they have specified Chicago-Wiggins Digester Covers and Gas Holders for more than 50 major installations. They'll tell you about the maximum gas pressures that are possible, the positive scum submergence and the non-tipping feature of Chicago-Wiggins Covers. They're sure to mention superior structural design which provides the highest live load safety factor of any cover. They will explain how lower ceiling plate stresses are achieved through modern welding and design; how a positive anti-rotation device keeps trusses always above tank corbels.

The features that have earned this preference by consulting and design engineers are yours when you specify Chicago-Wiggins Digester Covers and Gas Holders. Write Dept. H for complete details.



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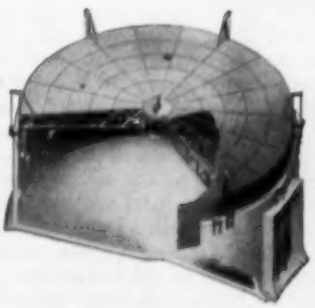

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Chicago-Wiggins Digester Covers and Gas Holders are products designed specifically for sewage digesters. They are the result of the combined experience of Chicago Sewage Engineers and Mr. John H. Wiggins, designer of the well-known Wiggins Floating Cover, of which more than 5000 have been built in the last 25 years.

adding lime to neutralize the acids.

Fine sand (60-100 mesh) will not settle out in grit chambers but will settle in primary sedimentation tanks. This settled sand will be removed with the sludge in the clarifiers and will be pumped to the digesters. Since there are no scraper mechanisms, the fine sand will collect on the sides of the cones in digestion tanks and gradually build up a hard layer which will not be removed with digested sludge, but will reduce the tank capacity available for sludge digestion. Dewatering and cleaning the tank is necessary.

Control

In addition to relatively close control of temperature, near 95° F, tests should be made to ascertain the volatile acid and alkalinity content and the pH of the liquor.

Sludge additions should be made at relatively constant rates to assure constant and uniform food supply for the active bacteria. The solids content of the sludge should be as high as possible to avoid unnecessary heating of useless cold water

Digested sludge withdrawals from the tanks should be at relatively low rates in order to avoid withdrawing good active seed material. Where two stage digestion is practiced transfer from the first to second stages should be at low rates and never in quantities that deplete the seed sludge in the first stage.

Observations of the character of the digested sludge help the operator to control the withdrawals. It is also possible to analyze the sludge for volatile matter content to determine whether or not digestion is complete. No definite value can be assigned to the relation between volatile acid content and the state of satisfactory digestion but 2000 ppm is probably the desired upper limit.

It has been found that there is a relatively stright line relationship between the volatile matter content of the raw sludge and the per cent reduction necessary to produce a well digested sludge. For example, in a raw sludge containing 80 per cent volatile matter, each 100 lb of dry solids contains 80 lb of volatile material and 20 lb of ash. If that sludge is decomposed to a well digested condition the 20 lb of ash will have associated with it 16 lb of volatile matter (i.e., it will contain 43 per cent volatile matter). Therefore the original volatile matter of 80 lb has been reduced to 16 lb or a reduction of 83 per cent.

Likewise when a raw sludge of 55 per cent volatile matter is digested to a satisfactory condition, it will contain approximately 45 per cent volatile matter or a reduction of approximately 33 per cent. A straight line can be drawn between these two points to predict the per cent reduction for other raw sludge of different composition.

Garbage Digestion

Ground garbage may be introduced into the sewer system from home garbage grinders, or it may be ground at a central location and introduced into the sewer system, or it may be ground at the sewage treatment plant and introduced directly into the sludge digester. The latter system produces the fewest operating problems at a sewage plant.

The amount of garbage contributed to the system is approximately 0.5 lb per person per day. Of this approximately 75 per cent is moisture. The dry solids, contain from 85 to 90 per cent volatile matter. When ground garbage is introduced into the sewers, there is an increase in grit removed in the grit chambers, and an increase in suspended solids and B.O.D. load on the plant.

Garbage solids digest well, but careful control of loadings is necessary to prevent volatile acid development. Combinations of garbage and sewage solids on a 1 to 1 ratio of volatile matter content can be easily handled. Gas production is increased as is the methane content of the gas.

Gas Production and Composition

The quantity and composition of the gas and the dissolved products can be mathematically predicted if one knows the composition of the organic matter undergoing digestion (i.e., the carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur content of the organic matter). Under normal conditions of operation the gas produced from sewage sludge contains 50 to 55 per cent CO_2 and 60 to 65 per cent CH_4, less than 1 per cent hydrogen and hydrogen sulfide combined and 2 to 5 per cent nitrogen (from dissolved air in raw sludge); it has a heat value of approximately 600 to 650 Btu. per cu ft. About 1 cu ft of gas is produced per capita per day.

Under optimum conditions of temperature (85 to 90 deg. F.) and pH (6.8 to 7.4), about 50 per cent of the gas produced will be given off in 24 hours, with the other 50 per cent evolved over the next 20 to 50 days (about 90 per cent in one week). Rate of gas production per day varies directly with temperature of the digesting mass.

Gas Utilization

Provision is generally made for collecting and utilizing the gases produce. Limited amounts of gas may be stored under either floating or fixed covers. Larger quantities may be stored in spherical pressure holders or gasometers.

Gas produced by slude digestion are quite usable for several purposes, principally for heating plant buildings, for heating sludge digestion tanks, for burning dried sludge, for internal combustion engines to produce power and for laboratory uses.

When used for heating buildings the gases are burned in a furnace equipped with dual burners to permit the use of oil when gas production is low. Dual burners are also required in furnaces for drying sludge and in external heat exchangers for heating sludge digestion tanks. Heat exchangers can operate directly from combustion of fuel or can be adapted for use where gas is utilized as a source of power for gas engine operation. In this case, engine jacket heat can be dissipated by circulation through the water bath of the heater.

One of the most profitable uses of sludge digester gas is to operate internal combustion engines for power production or to operate blowers in activated sludge plants, or to operate pumps. For normal gas production of approximately 1 cu ft per capita per day (650 Btu per cu ft), it is calculated that 2.5 hp can be produced for each 1000 persons. If garbage is digested this value is approximately doubled.

If the gas contains much hydrogen sulfide, it must be scrubbed or the corrosive action will be objectionable. The H_2S content should not exceed 0.07 per cent by volume or 50 grains per 100 cu ft. Hydrogen sulfide is removed in scrubber containing finely divided iron oxide held in wood shavings.

Gas engines for use on sludge gas may be obtained in sizes from 15 to 1800 hp. They may be connected to generators, air blowers, or sewage pumps through gearing. Hundreds of these engines are now in use in sewage plants. The dollar savings from the use of gas engines is appreciable. In one city of 30,000 population where diffused air aeration is used in the activated sludge process, the yearly "earnings" of gas engines was nearly $8000.

In many locations, dual-fuel engines are used. These are "diesel engines which use all oil on the diesel cycle or predominantly gaseous fuel with fuel oil ignition and are fully convertible from one fuel to the other." The use of these engines makes it possible to operate the power generating system (or blowers) continuously as desired in spite of variations in gas production.

Liming a Digester

By B. F. ROCKECHARLIE

Superintendent, Sewage Treatment Plant, Portsmouth, Va.

MUCH has been written pro and con concerning the use of lime in digesters. It seems that those who frown upon this practice are becoming increasingly vehement, but since it has been used at Portsmouth, Va., on several occasions to cure an ailing digester, it is believed that it can be of great help to others with similar operational setups.

Plan Facilities

The Portsmouth plant is a primary treatment plant with two-stage digestion and an external heat exchanger. The primary digester has three drawoff pipes at the bottom: one in the center, and one at each side. There are also three sludge inlet pipes: one at each side about half-way up the tank, and one at the top center. The other regularly used pipe is the automatic overflow, which leads to the secondary digester.

The primary tank contents are kept homogeneous by continually withdrawing sludge through one of the bottom pipes, passing it through the external heat exchanger, and back through one of the inlets. If no heat is needed, the hot water is diverted from the exchanger, but circulation is continued. The drawoff point is changed every 8 hrs., the inlet point being changed very hour.

Ordinarly, 10 min. pumping per hour of raw sludge (800 gal. at 5 per cent solids) is sufficient to keep the sludge drawn down in the sedimentation basins. Raw sludge is mixed with circulating sludge at a tee in the pipe gallery; no other heat is applied to the raw sludge. The temperature of the primary digester is maintained at 95° F. and the solids at about 5 per cent.

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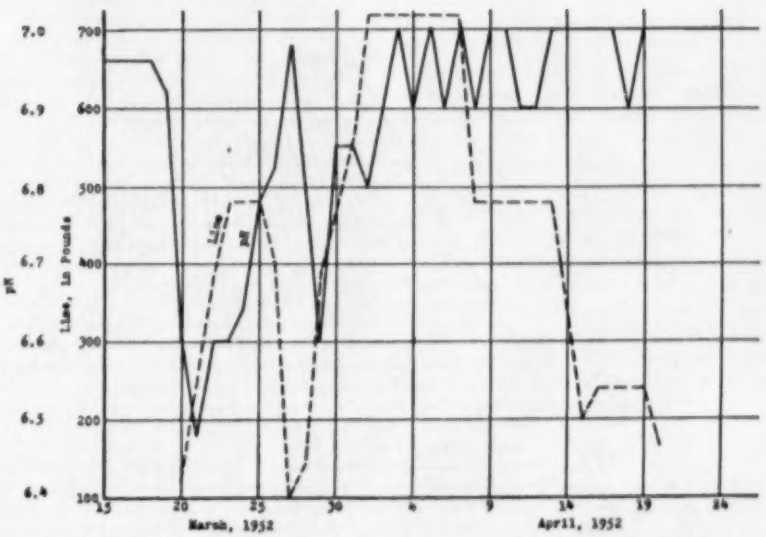


FIGURE 1.—Effect of lime addition to raw sludge on digester pH, Portsmouth, Va.

Liming

There are, of course, many things that can cause the pH of a healthy digester to start falling. Experience has taught that it is wise to begin liming before beginning to look for the trouble. It is not believed that moderate liming can harm a digester. Realizing that the word "moderate" is much too general, the following is presented as an indication of the manner in which the lime was introduced into the Portsmouth digesters during the period covered by Fig. 1.

From Rudolfs' lime chart[1] it was determined that about 20 lb. of hydrated lime per 800 gal. would be neded to bring the raw sludge (pH 5.8) to pH 7.3. On the hour, therefore, the lime was mixed in about 100 gal. of water in the scum pit and the solution was pumped to the digester. This was followed immediately by the regular 10-min. pumping of raw sludge, through the same inlet pipe. The next hour the same procedure was followed, using a different digester inlet pipe. Circulation of the digester contents was continued as in normal operation.

Fig. 1 shows that liming started with one-half the calculated amount per hour, and worked up to one and one-half times that amount, with at least 24 hr. at one rate of dosage. Lime dosages other than 240, 480, and 720 lb. resulted from changing the dosage rate during the day instead of at midnight.

Conclusions

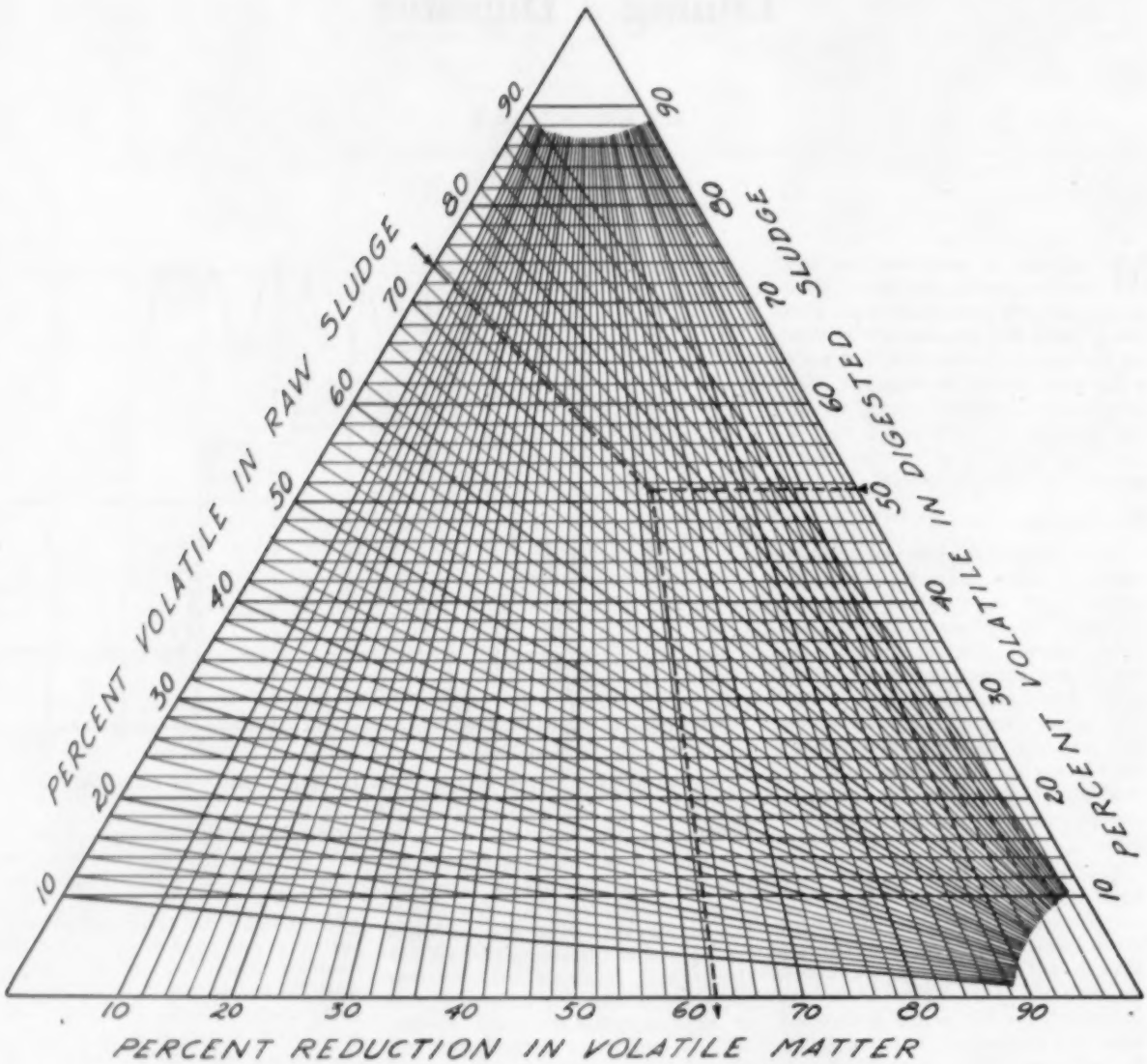
Many of the ailments that cause a falling pH cannot be cured with lime, but quite often these intangibles are difficult to pin down. It is suggested that at such times the liming program be initiated before proceeding with the diagnosis. The lime, if used moderately, can do no harm to the digester, and it may save one from the embarrassment of a driveway covered with foam.

Reference

1. Rudolfs, W., "Principles of Sewage Treatment." Figure 34, p. 75, Bull. 212, Nat. Lime Assn., Washington, D. C. (1942).

Chart for Determining Per Cent Sludge Digestion

By FRED H. BURLEY
Supervisor Sewage Treatment Plant, Detroit, Mich.



IT IS generally conceded that an excellent index to effective sludge digestion and efficiency of digester performance is the degree of conversion noted of the volatile matter in the sludge passing through the digesters. The degree of conversion is best expressed as per cent reduction of volatiles entering in the form of raw solids.

Volatile matter converted during anaerobic digestion is either evolved as gases or remains in the mother liquor (supernatant) as soluble organic or mineralized substances. The amount of gas produced is variously estimated at from 16 to 20 cu. ft. per pound of volatile matter converted.

The writer has found frequent computations of per cent reduction of volatiles on this basis to be a valuable check on digester efficiency, particularly so when considering the average figures for volatiles in the raw and digested products on the dry basis, from which the true reduction can be computed according to the following example. Assume:

	Volatiles	Fixed
Raw Sludge	73.5%	26.5%
Digested	51.2%	48.8%

Since in the raw sludge there was 73.5 lbs. of volatile matter for every 26.5 lbs. of fixed solids, there was originally present in the raw sludge $\frac{48.8}{26.5} \times 73.5 = 135.4$ lbs. of volatile matter for every 48.8 lbs. of fixed solids. Therefore, the actual reduction is 135.4—51.2=84.2 lbs. of volatile for every 135.4 lbs. entering as raw sludge. The reduction on a per cent basis is, therefore,

$$\frac{84.2}{135.4} \times 100 = 62.2 \text{ per cent.}$$

As a time-saver the accompanying chart was developed. It is simple to use. The arrows and dashed lines indicate the manner in which the per cent volatile in the raw and digested sludge (taking the above example) is located on two sides of the chart and the lines followed toward the opposite apex and parallel to the base, respectively, to their intersection. The line projected from this intersection to the base reveals the percentage reduction in volatile matter.

DEWATERING, DRYING AND INCINERATION

DIGESTED sludge (and raw sludge, as well as secondary sludge) contains a large amount of free water and in general cannot be disposed of until this free water is removed. (One exception is direct application of liquid digested sludge to farm land.) Therefore, the sludge must be dewatered before the final step in disposal. Dewatering may be accomplished on sand beds, by chemical coagulation and vacuum filtration, lagooning, and, in the case of raw sludge, by flotation through biological activity followed by filtration.

Sand beds or sludge drying beds are level areas of underdrained sand upon which the wet sludge is applied to a depth depending on the kind and character of the sludge. The applied sludge drains and dries with a rapidity depending upon the weather conditions and the character of the sludge. The "dried" sludge reaches a moisture content of 50 to 60 per cent, shrinks about 65 per cent in bulk and is spadable after ten days to three weeks. Freezing and thawing, and rain add to the speed with which water-binding colloids are removed from the sludge and hasten its dewatering, but where adverse winter conditions exist, covering of the beds with glass-roofed "greenhouses" makes it possible to carry on operations all year. The area of sand beds required may vary from about 0.5 to 2.0 sq ft per capita, depending on many factors. Most sand drying beds are used in conjunction with Imhoff tank installations or small plants where mechanical dewatering is too expensive.

Chemical Conditioning

Sludge conditioning or coagulation with chemicals is essential to the effective utilization of vacuum filters as a means of dewatering sludge. Upon the addition of conditioning chemicals, the colloidal matter in the sludge is "shrunk" and its water released so that it may be filtered. For raw, digested and chemical precipitated sludges, the common coagulants are ferric chloride and lime although aluminum chloride, and aluminum sulfates have been used with lime. For digested sludges the chemical consumption averages 2 to 3 per cent ferric chloride and 6 to 10 per cent lime (CaO). Raw sludge requires less chemicals; 1.3 to 1.5 per cent ferric chloride and 3.5 to 4.0 per cent lime. Activated sludges can be conditioned with ferric chloride alone, with 3 to 4 per cent of chemical. (All percentages are based on pounds of dry chemical to pounds of dry sludge solids.)

Elutriation

Elutriation is a process for the "washing" of digested sludge by passing the sludge counter current through a flow of clear water or sewage effluent. In this manner, decomposition products of digestion, particularly ammonium bicarbonate, are washed out of the sludge. Thus the alkalinity of the sludge is reduced and therefore less lime will be required for conditioning since much of the lime used reacts with the bicarbonate alkalinity. Elutriation also removes those chemical products which tend to stabilize the colloidal nature of the sludge. With the removal of these "peptizing" substances, the sludge can be coagulated more easily. The process was originated by A. L. Genter and has been installed at a number of plants throughout the country. Elutriated sludge requires little if any lime and only about 35 per cent as much ferric chloride as unelutriated digested sludge.

Vacuum Filtration

Vacuum Filters generally are drums which rotate on a horizontal axis, partly submerged in a tub of conditioned sludge. The deck of the drum is covered with a wire mesh or other solid covering over which is laid a covering of filter cloth. Wool cloth is used when lime is not used for conditioning, cotton cloth where lime is used. Synthetic cloths are also used. Vacuum is applied inside the drum for about five sixths of its rotation. Sludge particles are sucked against the cloth and form a cake. During rotation the free water is removed from the solids and discharged through a pump to the raw sewage influent. This liquid is clear and relatively free of B.O.D. and amounts to about 80 per cent of the volume of the digested sludge treated.

Before the filter drum completes its revolution the vacuum is cut off and air pressure applied to remove the cake from the filter cloth. A doctor blade is used to help remove the cake. On some filters a string discharge is used in place of air pressure and doctor blade, the strings which lie against the filter cloth for most of the revolution of the drum then leave the drum, after the vacuum is released, and pass over a separate roller at which point the sludge cake is discharged.

A variation of the string vacuum filter is the Komline-Sanderson Coiled Spring Filter. This filter is constructed with stainless steel decking over which two layers of coiled springs (like cords) are laid down in overlapping positions by means of rotating grooved cylinders. Vacuum is applied for 50 per cent of rotation, and the filtrate passes between and through the coils, which discharge over a roller and then are washed before returning to position.

The weight of the sludge cake removed may be determined from any filter by discharging the sludge cake onto a moving conveyor belt fitted with a device for continuously weighing and integrating the weight of the sludge on the moving belt.

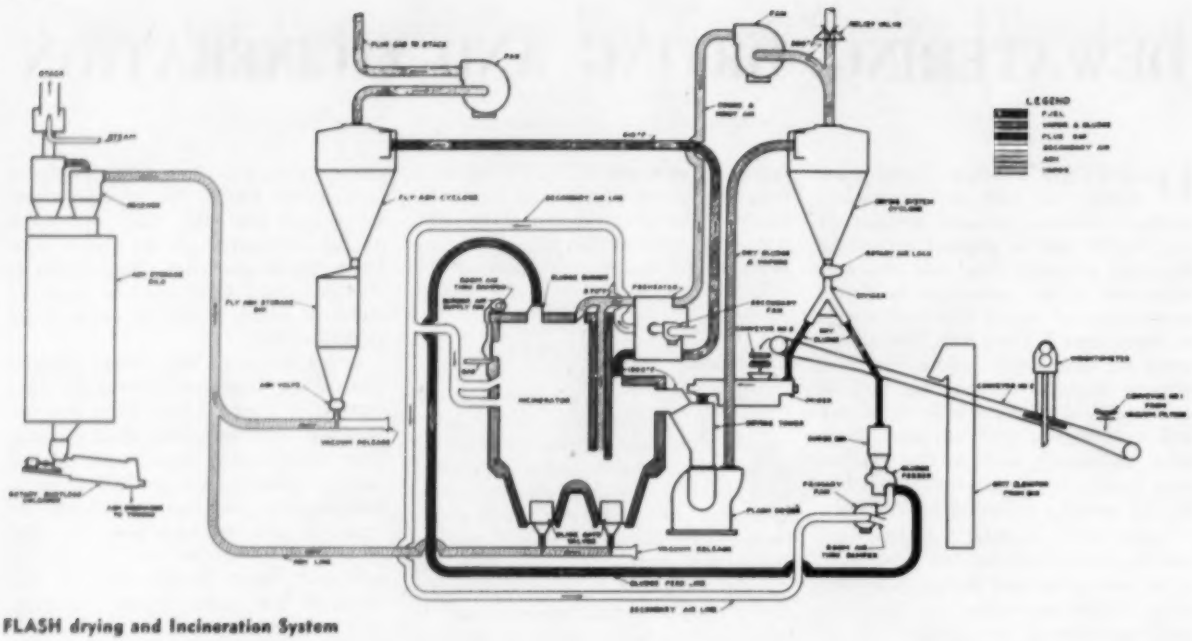
Flotation

Biological flotation is a process for the thickening of raw sludge without chemicals and conditioning it for ease of dewatering on vacuum filters. Experimental work of the Allegheny County Sanitary Authority at Pittsburgh, Pa., before construction of the plant indicated that at 20 to 35 deg. C., a period of approximately five days produced an acid fermentation and the formation of carbon dioxide bubbles which floated sludge solids to the surface of the tank from which they could easily be removed to vacuum filters. Raw primary sedimentation tank sludge of 5 to 8 per cent solids was thus concentrated to a solids concentration of 14 to 20 per cent. Subnatant liquor is clear and can be returned to the raw sewage. The solids are easily filtered to decrease the moisture content.

Drying and Incineration

In small installations, wet sludge cake may be hauled away to a fill, but in large plants, the cake may be dried (and used for fertilizer) or incinerated. Dryers of several types are available: Double-Shell, semi-direct heat, Louisville rotary, rotary louvre, atomizing, and flash dryers.

Incinerators are of two principal



FLASH drying and Incineration System

types, Raymond Flash Dryer system (Combustion Engineering) and the Multiple Hearth system (Nichols-Engineering and Morse-Boulger).

The Flash drying system dries and burns the sludge in a dustless, odorless combination of units, consisting of furnace, flash dryer, wet and dry sludge mixers, heat exchangers, and fly ash collector. Wet sludge cake is mixed with previously dried sludge from the hot gases in a cyclone, some being passed to the furnace where it is incinerated and some to the pug mill for mixing with wet sludge cake.

The multiple hearth incinerator consists of a refractory lined, steel jacketed circular unit containing four or more hearths, one above the other. Alternate hearths have openings at the center and alternate hearths have openings around the periphery. Rotating plows or rabble arms are attached to a hollow air-cooled vertical central motor-drive shaft and the teeth of the rabble arms break up the sludge and move it to the central or peripherial opening. In the Nichols Multiple hearth furnace drying takes place on the upper hearths.

In the "Martin Multizone" furnace (Morse-Boulger Co.) the top hearths are for drying, the middle hearths for incineration, and the bottom hearths for combustion. Vapors from the drying are drawn off and discharged into the combustion zone. In a modification of this furnace, wet sludge is added to the lower zone and is dried by downdraft from the incinerating zone, the dried sludge is then transferred by a conveying system to the top hearths.

This type of furnace has been used to burn thickened raw primary sedimentation sludge containing 85 to 90 per cent moisture. Although the heat value of raw sludge is higher (6000-7000 Btu. per lb.) compared to digested sludge (4000-5000 Btu. per lb.), this type of incineration requires more external heat (to evaporate the water) but it does eliminate the need for chemical sludge conditioning and vacuum filtration and the cost thereof.

In either type of furnace it is possible to obtain dried sludge or incinerated ash as desired. The ash is inert, finely divided, and can be used as fill. It has no residual nuisance characteristics whatever.

Lagoons

Lagoons, earth diked basins, have been successfully used as open digestion units(deep pit sludge digestion). Odors are relatively absent. Operation produces satisfactory sludge digestion and a clear supernatant liquor that can be discharged to streams. If the beds are used only for digestion, at least 0.17 cu ft is required per pound of solids added or roughly 0.017 cu ft per capita per day. If the lagoons are also used for dewatering as well as digestion, a capacity of 0.4 cu ft is required for each pound of solids added or 0.04 cu ft per capita per day, from which figure it is possible to calculate the approximate number of days required to fill a lagoon of known capacity.

Survey of Vacuum Filtration for Disposal of Sewage Sludge

Operating trends and process costs during the years 1941 to 1953

By JAMES M. MORGAN and JAMES F. THOMSON

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THE removal of any undesirable end-product from any process usually is costly as well as troublesome. Removal and disposal of sludge, as an end-product of modern sewage treatment processes, is no exception. In essence, the enigma of sewage treatment is the disposal of ever-accumulating sludge.

The disposal methods employed during the period of modern sewage treatment practice have been many and varied. Before sludge can be disposed of conveniently and safely, in and near populated areas which are its source, it should be dried to a suitable moisture content. The need to dewater great amounts of excess sludge arose at large activated sludge treatment plants. The removal of water from sewage sludge on sludge drying beds had been practiced earlier—with varying results. This practice was considered successful after a highly dewatered cake was produced; often considerable time was required to attain that end.

The removal of moisture from sludge makes it possible to transport the dewatered sludge in containers that need not be water-tight. When the water content of the sludge has been reduced to about 60-75 per cent, sludge may be readily handled with shovel or fork, and is easy to spread or work.

By far the speediest method of mechanically dewatering sludge is to remove the bulk of water through some type of filtration. In the United States, the most successful approach has been the vacuum filtration process. Other countries, notably England, generally prefer the filter press. When mechanical methods became practical (during 1920-1930) sludge filtration became popular not only for dewatering activated sludge but also for raw and digested sludges, chemical precipitated sludges, and combinations of these sludges.

Vacuum Filtration Practices

In the practice of vacuum filtration, hollow metal drums of varying lengths and diameters are covered with cloth (or suitable filtering material), supported over compartments connected both to vacuum and pressure systems. The drums are designed to rotate slowly in troughs of "conditioned" sludge. Vacuum is automatically applied to the compartments as they enter the trough, and this causes some of the sludge to adhere to the filtering material. As the drum rotates, vacuum is continually applied (see Fig. 1) through almost a complete revolution, thus dewatering the sludge by suction (20-26 inches Hg). At the necessary stage of drum revolution, the vacuum is released and pressure is applied to help remove the resulting ¼-in. to ⅝-in. layer of filter cake. The cake falls or is scraped from the filtering material onto a conveyor belt for removal to plant storage grounds; or it is conveyed directly to a waiting vehicle for local or long-distance delivery.

Attempts to filter untreated sewage sludge invariably fail. An initial layer of colloidal sludge solids builds up on the filter cloth and reduces its filtering ability.[1] To overcome this operating difficulty, conditioning of sludge is the usual practice. In the United States, sludge conditioning is by chemical treatment; in England conditioning has been achieved either through the use of chemicals or by excessive heating[2] and, on a laboratory scale, by freezing.[3]

Moisture in the resulting sludge cake depends upon the amount and nature of the conditioner as well as upon the type of sludge treated.

Conditioning of Sewage Sludge

Conditioning[4] of sludges usually refers to preliminary mechanical treatment and to the addition of chemicals or other substances preparatory to dewatering. Methods of treatment in general use are classified as: (a) Digestion, (b) Elutriation, and (c) Concentration.

Digestion

Digestion of sewage sludge is not practiced at all plants employing vacuum filtration, although vacuum filtration of raw sludges is infrequent. Where raw sludges are to be filtered, Fisher[5] recommended that a thickening tank with a 2-day sludge capacity be furnished. He also indicated that

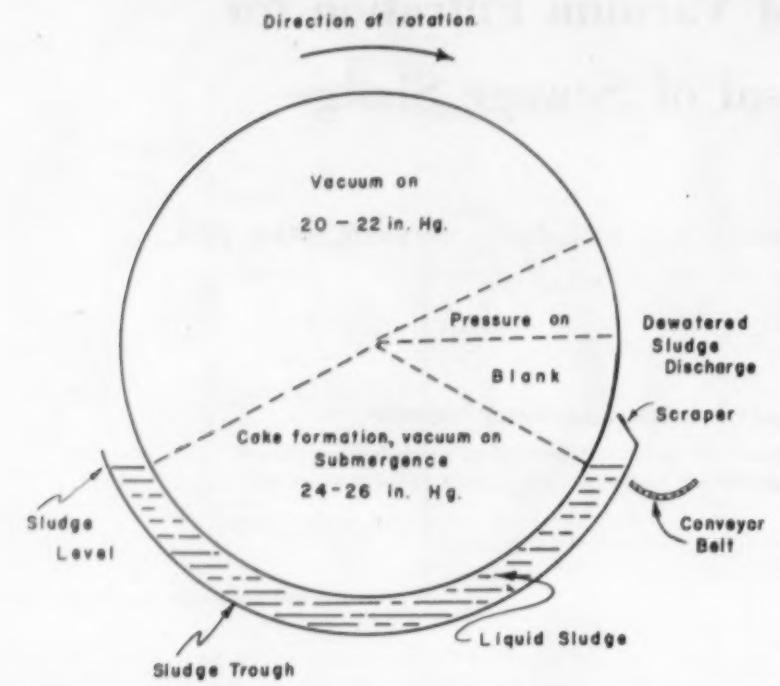
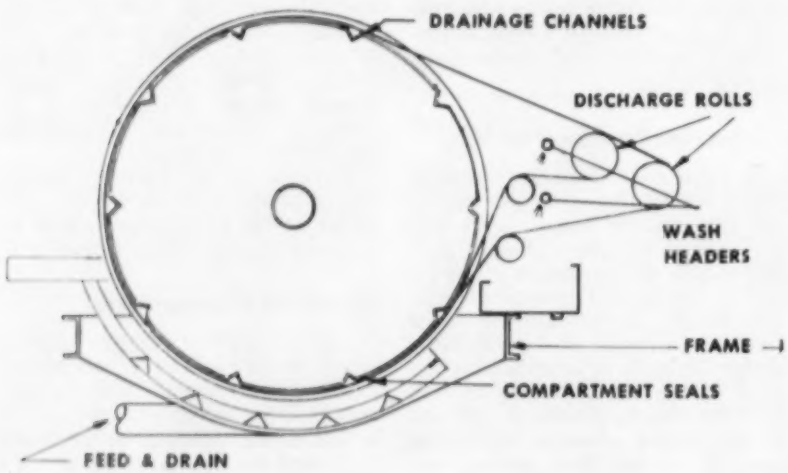


Fig. 1—BLANKET type of rotary vacuum filter for sewage sludge dewatering. This illustrates cycle of cake formation, vacuum application, and discharge.



Komline-Sanderson Eng. Corp.

Fig. 2—COILFILTER. Two layers of springs, lifted from the drum, are separated by discharge rolls and cake is discharged from upper layer.

sludge digested for only 20 days has better filtering qualities than one digested for a longer period. Our survey of sewage treatment plants in the United States shows that 21 plants practice sludge digestion at varying temperatures for periods of 30 to 90 days prior to filtration, and that the average digestion time is about 45 days for all plants reporting.

Elutriation

Elutriation is the process of "washing" sludge, using varying ratios of sludge to water. The process consists of running water and sludge into tanks, providing thorough mixing and a separation period of 2 to 6 hours, decanting the elutriate, and finally drawing off subsided sludge for further conditioning before filtration. Elutriation removes the amino-ammonia nitrogen[6] which interferes with sludge conditioning. This treatment is more effective with digested than with raw sludge. The elutriate usually is returned to primary settling units.

Experience at Washington, D. C., in a well designed and operated sewage treatment plant, has shown conclusively that elutriation has definite economic possibilities and is an acceptable conditioning process for filtration. The value of elutriation at this plant for the year 1941 was determined to be $11,015. In arriving at this value, construction costs, fixed charges, and patent right fees were included as were labor, materials, and cost of electric energy. This represented a 1.3c per capita savings in a population of 800,000. The savings actually resulted from a three-fold reduction in ferric chloride required for concentration. Fuhrman[7] concluded that, at this rate, the elutriation process would pay for itself within 4 to 5 years.

In 1941, Washington, D. C., was using a 1:3.8 ratio of sludge to water volume, with an average alkalinity decrease from 3,346 ppm in digested sludge, to 450 ppm in the elutriated sludge. In 1953, digested sludge was elutriated with Potomac River water at a ratio of 1:1.5, with the countercurrent method of washing employed. The alkalinity decrease in 1953 was the same as for a single wash at the ratio of 1:3.6.

Springfield, Mass., reported the highest elutriation ratio in 1953: a sludge to water volume of 1:4.5. Washington, D. C., already mentioned, had the lowest ratio.

Concentration

Substances that have been added to sludge to condition or concentrate it (either with or without elutriation and digestion) include the following: sulfuric acid, sulfur dioxide, alum, bone ash, peat, ground garbage, paper pulp, ashes, and clay.[8] The most universally employed materials are ferric chloride, lime, and ferrous sulfate.

In the operating year 1951-1952, Buffalo, N. Y., substituted 16 to 20 per

TABLE 1

Comparison of Data on Sludge Dewatering at Six U. S. Cities Reported for Years 1941 to 1953

	Washington, D. C.			Minneapolis-St. Paul			Buffalo, N. Y.		
	1941	1951	1953	1941	1951	1953	1941	1951	1953
Approximate Pop., mil.	0.8	0.92	1.04	.805		.907	.6	.6	.6
Sludge Dewatering, type	Prim. Dig. 30 days			Raw Primary, Conc. Only			Prim. Dig. 60 days		
Sludge Dewatering, dry tons	6,870		6,536	35,993		32,529	10,051		7,369
Total sewage flow, mg	39,568		59,843	39,286		45,706	51,262		49,976
Sewage susp. solids, ppm	180		207	315		256	168		174
Chemical Dosage, % dry sludge									
$FeCl_3$	3.18	3.6	4.0	1.53	0.98*	1.22*	2.93	2.85	2.19**
CaO				3.77	2.75	3.03	11.21	11.71	15.86
$FeSO_4$									
Chemical Costs, cents per capita	1.06		1.6	4.15		4.9	3.06		3.45
Chemical Costs, $/ton									
$FeCl_3$	39.00		64.00	38.21			31.80		80.00**
CaO									70.00
$FeSO_4$ (No Data)									
Filter Operations									
Number filters	4	4	4	6		8	3	3	3
Hours/year	4,705		3,822			38,919	6,320		5,893
Days/year	220		215			351	306		270
Filter cloth	Wool		90% wool-10% nylon	CF***		CF	CF		CF
Washing schedule	2 to 4 times per day			Cont.		Ea. Hour		Varies	
Economic cloth life (hours)	600	700	1,000	356		489	211		159
Cake yield, lb./sq. ft./hr.	5.9	6.8	6.8	58.8		65.3	6.77	7.81	5.00
Volatile matter in cake, %	44.4		45.0	3.82	2.98	3.0	42.9		55.9

* $FeSO_4$ used since June 1947, here expressed in terms of equivalent $FeCl_3$
** Aluminum chloride
*** Canton flannel

	Hartford, Connecticut			Annapolis, Md.			San Francisco, Cal.*		
	1941	1951	1953	1941	1951	1953	1941	1951	1953
Approximate Pop., mil.	.15	.228	.238	.015	.025	.028	.145	.180	.190
Sludge Dewatering, type	Prim. Dig. 30 days			Prim. Dig. 40-50 days			Prim. Dig. 60-90 days		
Sludge Dewatering, dry tons	1,296	3,763	3,010	173	342	252	888	3,570	3,005
Total sewage flow, mg	5,200	7,570	7,786		1,184	1,381	2,941	4,336	4,058
Sewage susp. solids, ppm	160	174	171		70	90	254	290	249
Chemical Dosage, % dry sludge									
$FeCl_3$	2.23	2.01	1.79		2.3	2.5	4.3	2.59	3.08
CaO									
$FeSO_4$				2.86					
Chemical Costs, cents per capita	1.72	2.45	1.59	0.71				1.00	1.10
Chemical Costs, $/ton									
$FeCl_3$	71.40		110.20				60.00	66.00	66.00
CaO									
$FeSO_4$ (No data)									
Filter Operations									
Number filters	2	2	2	1	1	1	1	2	2
Hours/year	994	1,110	891	710	588	362	1,682		1,362
Days/year	156	95	74	145	101	91	197		193
Filter cloth	Wool	Wool	Wool	Wool	Wool	Wool	Wool		Wool
Washing schedule		Once/run			Daily	Daily	3 times per day		
Economic cloth life (hours)	600	400	600	142	350	400	900	500	500
Cake yield, lb./sq. ft./hr.	7.5	6.5	6.33	7.5	5.1	7.9	5.4	5.0	5.0
Volatile matter in cake, %	39.8	41.5	50.0						58.6

* Richmond-Sunset Plant
1941 data from Genter, A. L., Transactions, ASCE, Vol. 72, No. 2, Part 3 (1945), pp. 246-247

Fig. 3—BLANKET type vacuum filters operating in one of Chicago's sewage treatment plants. There are 98 units installed.

cent aluminum chloride for 40 per cent anhydrous ferric chloride. Prior to adoption, the suitability of aluminum chloride was investigated experimentally. An industrial waste survey revealed an aluminum chloride conditioner to be present in the liquid discharge from a local chemical concern. At the same sewage treatment plant, a change was recently effected in adapting to sludge conditioning a waste lime slurry from an acetylene manufacturing plant. The slurry contains 20 per cent available CaO and the total solids range from 30 to 35 per cent. Pebble lime, containing approximately 90 per cent available CaO, is used whenever the slurry supply is short. Some of the items mentioned by Babbitt[8] may be employed in a few plants today on a modified scale.

The time of concentration required in treating various sludges depends upon the amount and combination of chemicals added, as well as upon the mixing rate employed. In practice, mixing times from 4 to 20 minutes are common.

Table 1, among other items, indicates the concentration of conditioning chemicals in use and results accomplished. The cities listed were selected on the basis of having available 1941 operating data. The authors consider that they offer an average cross-section of operating results.

Based on data from these cities, it appears that chemical dosages have not changed drastically in 10 or 12 years, though the trend appears to be downward. The suspended solids content of sewage has remained fairly constant, while the percentage volatile matter in sludge cake has moved slightly upwards. Cake yield from the filters has remained steady, and the yields do not necessarily become large with increased chemical dosage.

To indicate the flexibility of a large vacuum filter installation, the following example is included. In 1947, the Minneapolis-St. Paul sewage treatment plant was forced to change to ferric sulfate as a conditioner, since no bids were received on ferric chloride.[9] During the first five months of 1947, a dose of 0.91 per cent ferric chloride and 2.53 per cent lime (CaO) was employed. Table 2 shows the experience thereafter. These data illustrate how improvement in handling and feeding, coupled with careful operation, can maintain low materials usage, and therefore costs—even when sludge conditioners other than those originally specified must be

TABLE 2

Change in Conditioning Chemicals
Minneapolis-St. Paul

	Chemicals, Per Cent of Dry Sludge Solids		
	Ferric Chloride	Lime (CaO)	Volatile Organic, %
1942-1946 average	1.10	3.06	65.2
January-May 1947	0.91	2.53	
	$FeSO_4$ in terms of equivalent $FeCl_3$ for comparison		
June-December 1947	1.52	4.45	
1948	1.23	3.17	
1949	0.94	2.95	69.6
1950	0.98	2.95	69.3
1951	0.98	2.75	
1952	1.22	3.02	65.3

Komline-Sanderson Eng. Corp.

Fig. 4—COILFILTER type vacuum filters installed in York, Pa., sewage treatment plant for dewatering elutriated digested sludge.

used.

Raw sludge is easy to condition with low chemical dosages prior to filtration in the Twin Cities plant because: (1) the sludge has a relatively low volatile and high ash content; (2) a high concentration of solids is present, and (3) the water has a low alkalinity. Solids are unusually high at Minneapolis-St. Paul on a per capita basis.[10]

However, according to plant personnel, the quality of recent sludge appears to be deteriorating.[11] An increasing grease content in the sludge (from a low of 11.6 per cent in 1942 to a high of 20.1 per cent in 1952), and a decrease in smooth flowing and filtration qualities, are attributed to: (1) rapidly increasing use of detergents, (2) gradual increase in the use of garbage grinders, (3) increase of 19 per cent in per capita meat consumption over pre-World War II standards, with accompanying higher grease content, (4) delayed plant arrival of sewage solids due to an increase in size of sewer collecting system, and (5) growth of local soybean, linseed, and vegetable oil industry, as well as the grease discharged from a nearby ordnance plant.

TABLE 3

Sludge Dewatering by Vacuum Filtration
Cost Per Dry Ton—1953

	Washington, D. C.	Buffalo, New York	Columbus, Ohio	San Diego, California	Duluth, Minnesota
Approximate Population	1,040,000	600,000	500,000	450,000	80,000
Sludge Production, dry tons	6,536	7,369	6,360	2,327	194
Chemicals					
Ferric chloride	$3.10		$3.79	$4.58	$1.67
Lime		$1.62	2.54		1.38
Aluminum chloride		1.20			
Labor	3.91	6.81	5.32	7.44	5.75
Filter Cloth	0.14	0.25	0.47	0.36	0.34
Power	0.24	1.56	0.07	0.37	1.25
Total Unit Cost	7.39	11.44	12.19	12.75	10.39
Revenue from sale of sludge	*			6.65	4.80
Net unit cost	$7.39	$11.44	$12.39	$6.10	$5.59

* Negligible

Vacuum Filtration Costs

For exact comparison, costs are always difficult to cite accurately, since conditions and "bookkeeping" vary from community to community. Therefore, the costs, when they appear, should serve as indicative only. In Table 3 the unit cost breakdown, of sludge dewatering by vacuum filtration, shows that there is one item in common in most cities; i.e., labor charges account for the greater part of the filtration cost. Milwaukee, which spends by far the highest amount ($37.53 per dry ton) to produce a saleable item, also collects the largest return ($33.64 per dry ton) from the sale of its organic fertilizer, *Milorganite*. In 1953, approximately 69,000 dry tons of sludge were produced at a net cost of $3.89 per ton by this city; all of the sludge was sold directly as a fertilizer. Costs quoted are only for the sludge dewatering plant.

Revenue at Duluth, Minn., and San Diego, Calif., considerably reduces

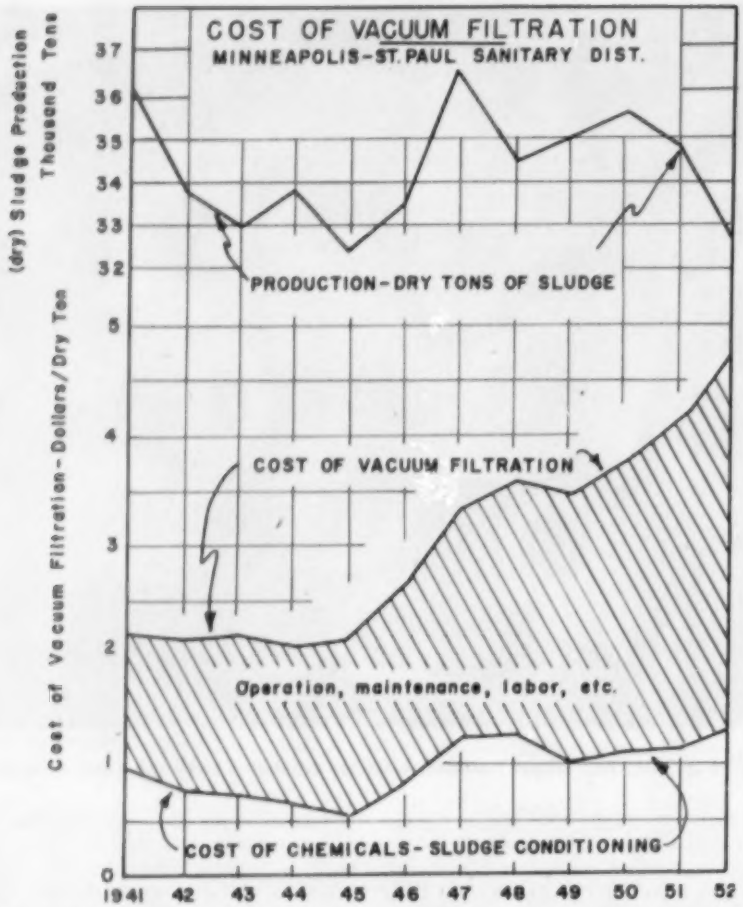


Fig. 5—GRAPHICAL comparison of data, 1941 to 1953, for vacuum filtration of sewage sludge at Minneapolis-St. Paul.

the net unit cost of vacuum filtration. It is also interesting to note that total unit costs per ton, of dry sludge solids, excluding capital investment, were approximately the same for Buffalo, Columbus, and San Diego, all of which have approximately a one-half million population.

Table 1 gives an indication of essential items in vacuum filtration practices in the United States. It is interesting to note that in all plants practicing elutriation, the chemical costs per capita were lower than Minneapolis-St. Paul; in the latter city elutriation is not practiced—the raw primary sludge is concentrated only. Also, the "medium-size" cities enjoy as favorable as per capita outlay for chemical costs as do the larger metropolitan areas.

English experience during 1949 at the Halifax Sewage Treatment Plant, where sludge is conditioned by heating to approximately 360° F., showed the cost of treatment per ton of dry solids to be 46 s. 10 d. ($6.56).[12] The cake was not filtered, but was "squeezed" in a Johnson Press.

Figure 5 illustrates a 12 year record of vacuum filtration costs at the Minneapolis-St. Paul Sewage Treatment plant.[13] During that period, sludge production varied from a minimum of 32,482 dry tons (in 1945) to a maximum of 36,663 dry tons (in 1947). Using 1941, the last pre-World War II year as a base, the unit cost of chemicals per dry ton for sludge conditioning rose from $0.93 to $1.37 in 1952, an increase of 47 per cent. During the same period the cost of operation, maintenance, and labor rose 178 per cent. Each year after 1941 showed a steady rise in operation, maintenance, and labor costs, with only a slight evidence of a drop in 1944. This is perhaps indicative of most cost trends in the United States during the years considered.

Operation of Vacuum Filters

As far as is known, filter operations are not continuous in any of the large or small United States sewage plants employing vacuum filtration. Approximately 5 to 8 hours of filter runs daily will dewater the collected sludge, and this rate is usually maintained for 5 or 6 working days per week. Total annual filter runs from 900 to 2100 hours were reported. Runs of greater length are not common. All cities listed in Table 1 use either wool or Canton Flannel filter cloths (or a combination of wool and nylon) supported over the drum on wire meshes.

Liberty, N. Y., (not included in table) employs a coiled spring unit (Komline-Sanderson) with two drying drums, each 8 ft. in diameter and 6 ft. long. The coils lay down in overlapping positions giving two complete layers. The drum rotates with vacuum applied 50 per cent of the time from dead center bottom to dead center top. In this position the spring acts as a filtering device and later, after reaching dead center top, the springs are stripped mechanically from the filter and flexed. Stainless steel fingers strip the cake from the coils, complete cleaning being aided by the flexing operation which is con-

TABLE 4
Per Capita Sludge Production at Seven U. S. Cities

City	Population* in millions		Sludge product'n, dry tons		Sludge product'n, pounds per capita		Percent Change Per capita	
	1941	1953	1941	1949-53 Ave.	1941	1949-53 Ave.	Pop.	Sludge Prod.
Buffalo, N. Y.	0.6	0.6	10,051	8,462	33.5	28.2	0	— 15.8
Minn. - St. Paul, Minn.	0.8	0.9	35,993	34,527	89.5	81.2	+ 12.7	— 9.3
Washington, D. C.	0.8	1.0	6,870	6,506	17.1	14.1	+ 30.0	— 17.5
Annapolis, Md.	0.025	0.028	173	472	13.8	36.8	+ 12.0	+ 166.3
Hartford, Conn.	0.150	0.238	1,296	3,668	17.3	32.1	+ 58.8	+ 186.0
San Francisco, Cal.**	0.145	0.190	888	3,374	12.3	37.2	+ 31.0	+ 202.0
Springfield, Mass.	0.130	0.140	946	1,875	14.6	26.5	+ 7.7	+ 81.5

Note: 1941 information from Genter, A. L., Transactions, A.S.C.E., 1945, Vol. 72, No. 2, Part 3, pp. 246-247

* Approximate sewered population

** Richmond-Sunset Plant

tinuous. Liberty is a summer resort and the summer population doubles the full-time number of winter residents from about 7,000 to 15,000. The unit has been satisfactory to date.[14]

During 1941, the vacuum filters in Washington, D. C. were washed for 30 to 45 minutes after each operating period to remove particulate matter that had a tendency to blind the cloth. On a regular basis, the cloths were washed for 24 hours in a 1 per cent oxalic acid solution. This operation increased the service of wool cloths from 528 to 682 hours on the average, or about 30 per cent. On the basis of a first cost of $120 per filter cloth, the hourly cost of operation was reduced from $0.23 to $0.18.[15]

In 1953, Washington installed 90 per cent wool—10 per cent nylon filter cloths; these filters were washed from 2 to 4 times each operating day. During 1953 all four cloths were replaced, but after an average service of about 1100 hours. Filter cloth cost per dry ton during the year averaged $0.14. Two of the four replacements were made with 100 per cent nylon cloths. Results of new cloth trials are not yet available.

Each vacuum filtration plant has its own schedule for washing filters, and uses varying pressures of water. The range of filter washing in 1953 was reported to be from an hourly basis to every 14 hours of operation.

Hourly vacuum filter washing has shown promise in Milwaukee. The filter washing times tested have varied from once every 24 hours to continuously. Continuous spray washing with plant effluent at 65 to 70 psi pressure did not prove desirable. Hourly washing at 30 to 50 psi helped maintain a cleaner filter media. The following data list the complete washing cycle practiced in Milwaukee:[16]

Plant started	Washing Time	Pressure
1938	Every 24 hours	(?)
1942	Every 8 hours	(?)
1947	Continuously	65 - 70 p.s.i.
	Every hour	30 - 50 p.s.i.

Our survey showed that filter cloth expenses varied from about 2 to 4 per cent of the unit cost of vacuum filtration on a dry ton basis. When rates of filtration are high, filter cloth costs increase, as do the chemicals required to effect proper filtering.

Municipal Sludge Production

According to the most recent information, a U. S. population of approximately 92 million contributes sanitary sewage to sewers. Of this number some 62 per cent, or 57 million, sends domestic waste to systems that will eventually reach sewage treatment plants of one description or another.[17]

Questionnaires were sent during 1953 to 15 cities throughout the United States with a total population of 4,907,000. Replies indicated that about 78,000 tons per year of dry sludge were produced in those cities. This is equivalent to a contribution of 32 pounds of dry sludge per capita per year. These figures do not include Milwaukee, since the sludge production from that city is abnormally high. The population of cities included in the total mentioned ranged from 28,000 to slightly more than 1,000,000.

Table 4 indicates that for cities over one-half million in population, the sludge production on a per capita basis has declined since 1941. In smaller cities, with one-quarter million or less population, the reverse is true. These figures are from plants that employ vacuum filtration as a method of sludge dewatering, and do not necessarily represent a per capita trend in all American cities.

A considerable quantity of sludge that is dewatered by filtration eventually finds ultimate use as land fertilizer, either as a commercial fertilizer filler or as a lawn dressing. The return from sludge sold for these purposes seldom cancels operating charges necessary to prepare the end-product for sale.

Chemical Composition of Sludge

The composition of digested sewage sludge varies from place to place. Analyses of many hundred pre-1945 samples collected throughout the United States show the following percentage ranges and averages:

	Range	Average
Ash	36 - 58	49
Volatile	42 - 64	51
Nitrogen as N	1 - 4.5	2.2
Phosphorous as P_2O_5	0.6 - 5.7	1.5
Potash as K_2O	0.3 - 1.6	0.7
Grease and Fats	3 - 17	8

Ten vacuum filtration plants in the U. S. have furnished complete or partial chemical analyses for the 1953 operating year. Two of the plants, Dearborn and Milwaukee, do not employ digestion preliminary to vacuum filtration.

Table 5 shows ranges as well as arithmetic and weighted averages of chemical analyses for 1953. Since the values submitted for Milwaukee covered a period of seven years (1945-53), figures for that city were included in two calculation but omitted from the last. It is interesting that the ash and volatile arithmetic averages shown above and in Table 5 coincide.

The 10-plant arithmetic and weighted averages show that 1953 sludge, for the plants reporting, has a greater nitrogen, phosphoric acid, and grease content than the pre-1945 values. On the other hand, potash in Rudolfs' averages is greater than twice the 1953 value.

Weighted values, without the 1947-53 Milwaukee determinations, show a completely different set of figures when compared with pre-1945 or 1953 values. Volatile content is high, while nitrogen, phosphoric acid, and potash fall considerably below the pre-1945 and 1953 averages.

Units Not in Use

In addition to the statistical information received, the following comments were reported from five widely separated areas:

TABLE 5
Constituents of Vacuum Filtered Sludge—1953

Analyses Reported as Percent on Dry Basis

Determination	Range[1] Minimum	Range[1] Maximum	Averages Arithmetic	Averages Weighted[2]	Averages Weighted, without Milwaukee (1947-52)
Ash	25.6[a]	70.0[b]	49.0	37.1	33.9
Volatile	30.0[b]	74.4[a]	51.0	62.9	66.1
Nitrogen as N	1.7[b]	6.34[a]	3.49	3.14	1.90
Total Phosphoric Acid as P_2O_5	1.2[a]	3.86[b]	2.42	2.52	1.83
Potash as K_2O	0.09[c]	0.57[d]	0.30	0.42	0.35
Grease	7.0[e]	36.2[c]	11.7	12.4	11.4

1. Includes: Aurora, Ill., Buffalo, N. Y., Dearborn, Mich., Duluth, Minn., Hartford, Conn., Milwaukee, Wis., Richmond-Sunset Plant, San Francisco, Cal., San Diego, Cal., Washington, D. C., and Worcester, Mass. Combined approximate sewered population = 4,113,000.
2. Population times constituent for each city divided by total population reporting.
a = Milwaukee, b = Hartford, c = Buffalo, d = San Diego, e = Washington.

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Close up of cone showing fixed inverted 'bowls' and revolving stoker with arms.

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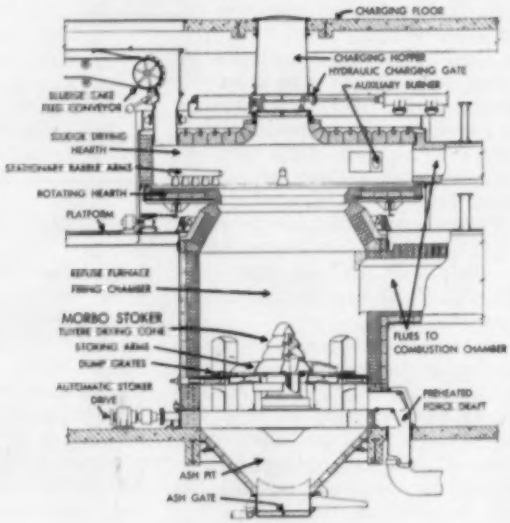
This type unit is ideal for the smaller community which must dispose of sewage sludge as well as municipal refuse. The sludge is dried on the upper hearth and then rabbled (stationary arms and revolving hearth) into the lower chamber where it is incinerated with the refuse. Very compact plant and economical in both first and operating costs.



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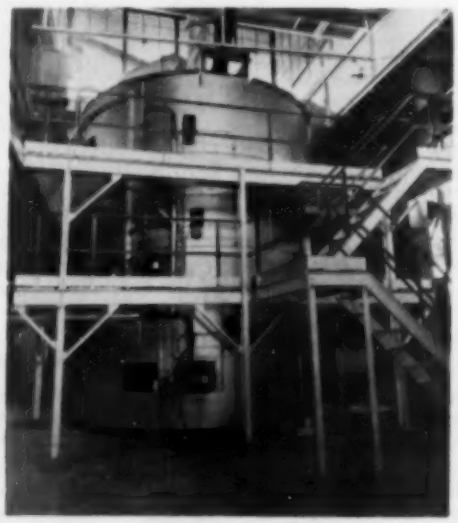

Marion, Ind.: "One filter that is not used" was the reply to the question concerning the number of filters in operation. "All sludge is hauled in liquid form by tank trucks and sprayed on farm land, the sludge being disposed of by sale as a soil conditioner."

Oklahoma City, Okla.: "No filters used at the Northside Sewage Treatment Plant since 1950."

Pasadena, Calif.: "The disposal of sludge by filtration and drying was discontinued in 1942, since which time the sludge has been disposed of by contract through the facilities of the Los Angeles County Sanitation District." In 1948, the City of Pasadena discontinued the operation of its sewage treatment plant entirely.

Wisconsin Rapids, Wis.: "The use of vacuum filtration was discontinued about 10 years ago. We now use open sludge beds."

Rock Island, Ill.: "At Rock Island we have two filters, size 4-ft. x 6-ft. They are not used. These sludge filters have been standing still for the last ten years. Then engineer of the sewage treatment plant in 1942 said it cost to much to operate the filters . . ."

Summary of Survey Data

The disposal of constantly-accumulating sludge in sewage treatment processes is an essential and costly operation. Vacuum filtration is a rapid method of dewatering sludge to facilitate disposal. Digestion, elutriation, and concentration, singly or in conjunction, usually precede filtration.

The average sludge digestion time used in U. S. plants employing vacuum filtration from 1941 to 1953 was about 45 days, with a range of 30 to 90 days. Elutriation, less widely used than digestion, reduces the amount of chemicals required for concentration, and lowers the alkalinity of digested sludge. A counter-current method of washing sludge has reduced the volume of water necessary to produce a specific alkalinity reduction.

Several chemicals, notably ferric chloride and lime, are widely used as conditioners. Two large sewage treatment plants have ceased using ferric chloride: a northeastern plant used aluminum chloride which was discovered in a waste discharged from a local chemical concern, and substituted lime slurry from a nearby acetylene plant; a mid-western sewage plant adopted ferric sulfate, used in conjunction with lime, when no bids were received on a proposal to furnish ferric chloride. Flexibility of changeover from original specified materials to other chemicals is noteworthy. The same mid-western plant is experiencing a definite change in sludge quality because of modern consumer and homeowner habits.

Revenue from the sale of sewage sludge as commercial fertilizer or lawn dressing seldom equals vacuum filtration operation and maintenance costs. Excluding fixed charges, total unit cost in 1953 for dewatering sludge by vacuum filtration varied from $7.00 to $13.00 per ton of dry solids, with revenue from the sale of sludge infrequently reducing these figures. One English experience of 1949 approaches the lower cost limit.

In comparing data from six cities, the per capita chemical costs for sludge conditioning were lower where elutriation was practiced. Chemical costs have risen since 1941. A breakdown of individual items shows that labor accounts for the largest expenditure in vacuum filtration on a dry ton basis; an increase of about 180 per cent in labor, maintenance, and operation costs was reported in one instance.

Annual filter operating periods from 900 to 2100 hours have been reported throughout the period under discussion. The average life of filter cloths appears to be 400-600 hours during this period. Of the plants reported, only one has experimented with any new filter media; i.e., a 90 per cent wool—10 per cent nylon cloth, which was in successful operation in 1953 for about 1100 hours per cloth. The 100 per cent nylon cloths now are being used experimentally. A coil spring filter, of indefinite life, is mentioned. Filter washing, using different water pressures, has varied from continuously to every 24 hours throughout the operating period.

Annual sludge production data reported by 15 cities, varying in size from 28,000 to 1,000,000, and having a combined population just under five million, averaged 32 lb. per capita on a dry basis, during the year 1953. This production compares with 42.4 lb. per capita production during 1941 based on data reported by seven cities having a combined population of 2.5 million. Average sludge production in the same seven cities during the period 1949-53, with population increased to three million, had dropped to 38 lb. per capita per year. A percentage decrease in sludge production was noted in cities over one-half million in size; cities one-quarter million or less showed increased per capita sludge production.

An arithmetic average of 1953 sewage sludge analyses, representing a population of approximately four and one-half million persons, indicates that sludge is becoming richer in chemical content, but has a higher grease content, when compared to pre-1945 sludge constituents.

Acknowledgements

Many sewage treatment plant superintendents and other municipal officials contributed to making this study possible; the names are too numerous to list here, but their efforts are appreciated. Special acknowledgement is due to Dr. Abel Wolman and to Dr. John C. Geyer, of the Department of Sanitary Engineering, Johns Hopkins University, for their assistance and many suggestions during the course of the study.

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UTILIZATION OF SEWAGE SLUDGE

BECAUSE sewage sludge contains a high percentage of organic and humus matter, much thought has been given to the use of sludge as a fertilizer or soil conditioner. In evaluating fertilizer characteristics of sludge, there are five types of sludge to be considered: Raw (primary), digested, activated, digested activated, and chemically precipitated. Analyses of various types of sludge are shown in the accompanying table.

Analysis of Various Types of Sludge*

Percent-Dry Basis

Constituent	Types of Sludge				
	Raw	Digested	Act. Sludge	Filter Cake Raw	Filter Cake Digested
Volatile Material	60-80	45-60	62-75	55-75	40-60
Ash	20-40	40-55	25-38	25-45	40-60
Insoluble Ash	17-35	35-50	22-30	15-30	30-45
Grease and Fats	7-35	3-17	5-12	5-30	2-15
Protein	22-28	16-21	32-41	20-25	14-30
Ammonium Nitrate	1-3.5	1-4	4-7	1-3	1.3-1.6
P_2O_5	1-1.5	0.5-3.7	3-4	1.4	0.5-3.5
K_2O		0-4	0.86		
Cellulose, etc.	10-13	10-13	7.8	8-10	8-12
SiO		15-16	8.5		
Iron		5.4	7.1		

*Data from FSIWA MOP No. 2.

At best, any type of sludge is lacking in some respects as a complete fertilizer. As can be seen from the table, the nitrogen, phosphorous and potash contents are lower than those of commercial fertilizer, but the humus content is of value for soil conditioning. In addition, sludge contains amounts of trace elements and growth promoting substances of value to soil conditioning. These trace elements include copper, zinc, manganese and magnesium. Generally, it is considered that dried activated sludge is better than digested sludge and that raw sludge should not be used on soil, for fertilizing purposes, because of possible contamination of products grown therein.

Perhaps the best known sludge sold as fertilizer is Milorganite from Milwaukee, Wis., although Chicago and other cities also sell activated sludge and a number of cities sell digested sludge. Marion, Ind., has sold digested sludge directly from digestion tanks without dewatering for delivery and application directly on farm land. Since the sludge is not dried the soluble ammonia nitrogen is not lost, as it would be on drying.

Preparation of the dried sludge for sale is essential to increasing its salability. Heat dried sludge is pulverized to granular size during the drying. Open bed dried sludge must be disintegrated.

According to data collected by the U. S. Dept. of Agr., collected between 1936 and 1944 approximately 100,000 tons of dried sludge was used each year. The revenue to be obtained from the sale of sludge varies. In many cases, the revenue may not cover the cost of producing and selling the sludge, but this method may still be less costly than other methods of disposal. For a complete discussion of this subject, reference should be made to "Manual of Practice No. 2—"Utilization of Sewage Sludge as Fertilizer" published by the Federation of Sewage and Industrial Wastes Assn.

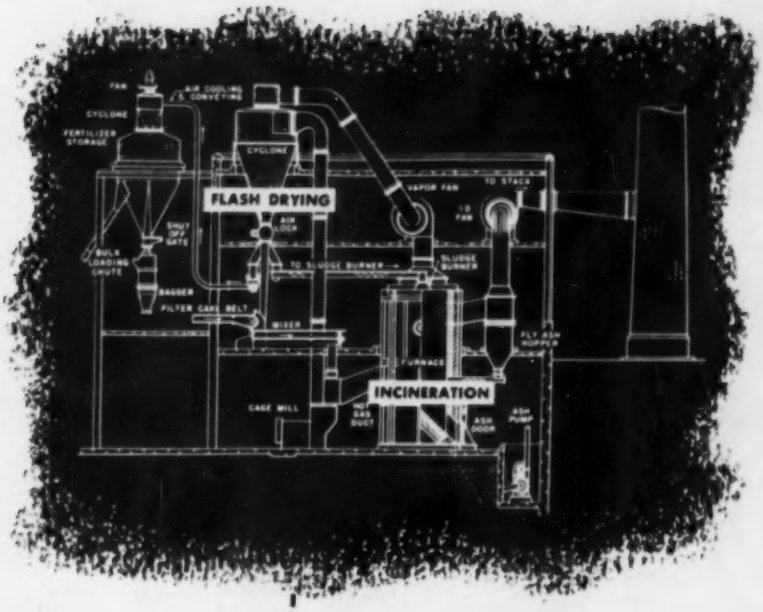
When adequate land area is available and the amount of sludge is relatively small, the problem of ultimate disposal of sludge is of little import. Where disposal areas are limited the amounts of sludge are great, ultimate disposal of the solids from sewage treatment may be a problem of some magnitude. Thus preparation and sale of fertilizer or incineration may be the best solution. Economic factors dictate the type of ultimate sludge disposal.

Many persons regard sewage sludge as a soil conditioner or soil builder, rather than a fertilizer in the strictest sense. In some states the legal definition of a fertilizer precludes the possibility of classing sludge as a fertilizer because the chemical constituents are below the legal specifications.

In a few cases, dried sewage sludge has been fortified with nitrates, potash and phosphates but in general there is no economic gain, it is as easy to buy and spread both the sludge and the fertilizer.

Heat dried activated sludge appears to be the best partly because it is free from weed seeds, blends quickly and easily with the soil and has but a very slight odor. Lawns fertilized with sewage sludge have a dark green color and a strong stand of grass.

Transportation of sludge to the consumer presents one of the big problems and is a factor in the economics of the sale of sludge by a sewage treatment works.



SOME FACTS ABOUT THE HEAT DISPOSAL of SEWAGE SLUDGE

Even though dried sewage sludge can often be sold at from $5.00 to $20.00 a ton – remember that is not *always* the case.

If sewage is contaminated – with grease, fiber, etc., for example – you may find the *only* thing to do is to incinerate the sludge. On the other hand, even though the sludge may not have the highest chemical analysis for fertilizer – it still can be marketed as a soil conditioner – thereby eliminating the ash disposal problem.

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1. **Flash Dry sludge.**
2. **Flash Dry and Deodorize.**
3. **Flash Dry and Incinerate.**
4. **Flash Dry, Incinerate and Deodorize.**
5. **Incinerate only.**
6. **Incinerate and Deodorize.**
7. **Flash Dry and Deodorize in conjunction with refuse and garbage incineration – plus incineration of sludge if desired.**

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ALSO FLASH DRYING AND INCINERATION SYSTEMS FOR INDUSTRIAL WATER DISPOSAL

Sludge As a Soil Improver

Value of pH control and toxicity of minor elements

By HERBERT A. LUNT
Soil Scientist, The Connecticut Agr. Expt. Station, New Haven, Conn.

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Now the subject of sludge utilization in agriculture has been rather extensively treated in the literature*, yet there are many questions still to be answered. Furthermore, although our interrogator may be familiar with results obtained, say, in Minnesota, Illinois or Texas, he wants to know what the score is in Connecticut.

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The experimental procedure usually followed was to apply fresh sludge to the soil and work it in, and at the same time apply a more or less standard treatment of commercial fertilizer such as 5-10-10 at fairly high rates as is customary in market gardening. If lime was needed, it too, was added at the same time. The seed was sown within a day or two. The soil was successively cropped, usually to spinach and beets alternately. No further applications of sludge were made but commercial fertilizers were applied as needed. In some cases rye or oats was seeded as a cover crop. Later on oats and beans were grown on an acid soil series.

These experiments were carried out (a) in two-gallon greenhouse pots, (b) in outdoor concrete soil boxes or frames (without bottoms, i.e. the soil in the frames rested directly on the natural subsoil), and (c) in small field plots.

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The two sludges chosen for the initial work were from the cities of New Haven and Torrington. New Haven sludge produced in the Boulevard plant, is primary digested sludge conditioned with ferric chloride and lime for vacuum filtration. As taken from the conveyor belt the pH is about 11, but upon standing it drops to 7.5 or 8.0. It normally contains industrial wastes orginating largely from textile dyeing works.

The Torrington sludge is also a primary digested sludge but instead of being chemically conditioned for filtering, it is air-dried on open sand beds. It contains industrial wastes originating principally in textile and metal industries.

Upon completion of the digesters at the West Haven plant in 1951, some experiments were started with sludge from that source. West Haven sludge is a primary digested sludge elutriated and then conditioned with ferric chloride for vacuum filtration. It contains no appreciable industrial wastes.

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Variable Response of Plants to Sludge

Our earlier work, (1943-1946) had shown disconcertingly variable results, ranging from appreciable yield increases on the one hand to retardation of growth on the other. The present study in its initial stages showed similar variabilities. In the first experiment in the greenhouse with Cheshire loam soil, both New Haven and Torrington sludges resulted in reduced yields of beet roots, although top growth was satisfactory. Later beet crops showed gradual improvement and, in the last crop, beet root yields were increased 7 to 22 per cent by the sludge treatment. Spinach was particularly poor, the first crop being almost a complete failure.

On the other hand, our outdoor experiments in the soil frames with similar soil showed New Haven sludge producing the highest yields, 81 to 86 per cent better than the checks, and Torrington sludge the lowest,—in some cases a complete failure. The second year's crop (1951) followed the same pattern. And on the field plots at the farm on Cheshire loam soil, New Haven sludge produced higher corn yields than the checks (no Torrington sludge was used on these plots).

Admittedly the rates of application were high, particularly in terms of the amount of nitrogen applied. The original objective was to apply the same amount of organic matter as is present in 10 and 20 tons of dry wood chips. To apply 10 tons of organic matter meant using about 20 tons (dry weight) of New Haven sludge and 35 tons of Torrington sludge[1] per acre. The fact that under certain conditions excellent yields were obtained indicates that the rates of application were not excessive.

Influence of pH

But why was New Haven sludge detrimental in some cases and very favorable in others? Fortunately the answer was soon found: the pH of the soil. The alkaline New Haven sludge effectively held up the pH in the frames, but due to the artificial condition in the greenhouse the sludge did not prevent acidification of the potted soils. On the other hand, the acid Torrington sludge contained no lime to deter the development of a more acid condition as nitrification progressed.

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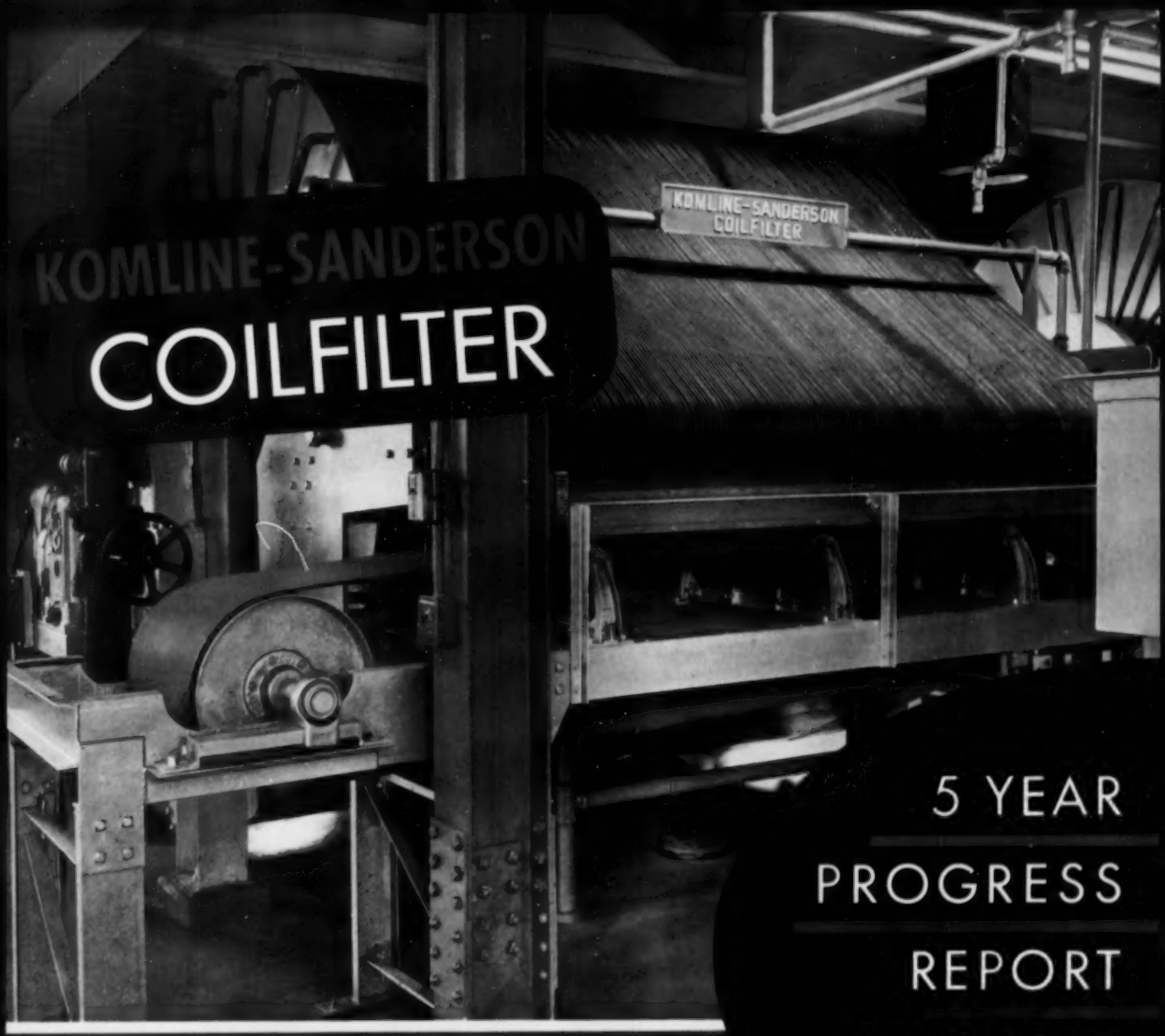

KOMLINE-SANDERSON

COILFILTER

5 YEAR

PROGRESS

REPORT

1949-1954

The Modern

SLUDGE VACUUM FILTER

For Modern Municipalities

KOMLINE-SANDERSON ENGINEERING CORPORATION

Peapack, New Jersey

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Proved performance..for better sludge dewatering

- NON-CLOG
- PERMANE
- CONSTA
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Four 300 Sq. Ft. COILFILTER units at the Komline-Sanderson plant in Peapack, N. J. before shipment to the Miami, Florida, sewage treatment plant. Engineers —Metcalf & Eddy: Rader Knappen Tippetts: Maurice H. Connell & Associates, Inc.

A COILFILTER installed in a glass-enclosed drying bed, which is replacing 100 Sq. Ft. unit at Mt. Penn, Penna. Engineers—Gilbert Associates.

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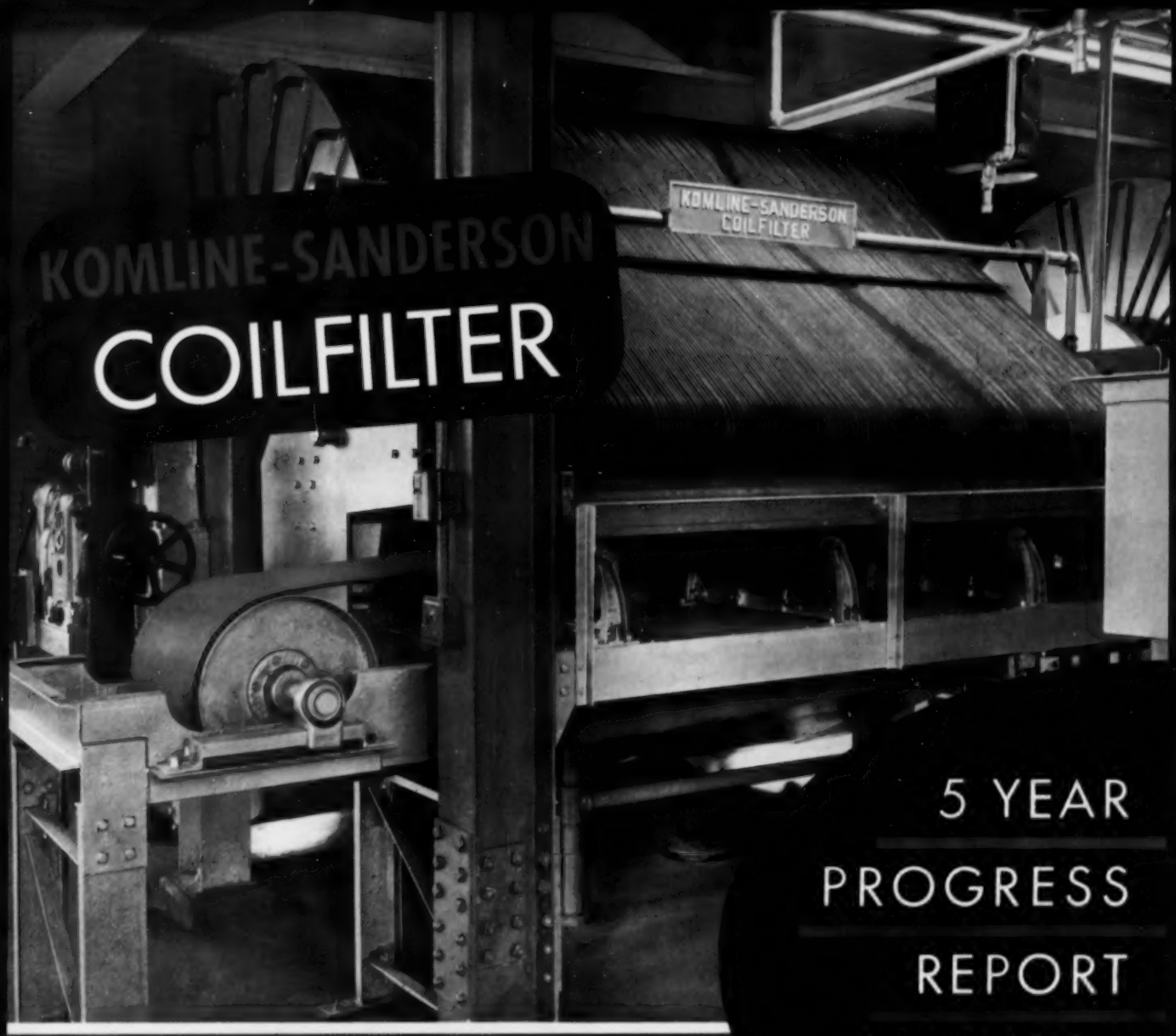

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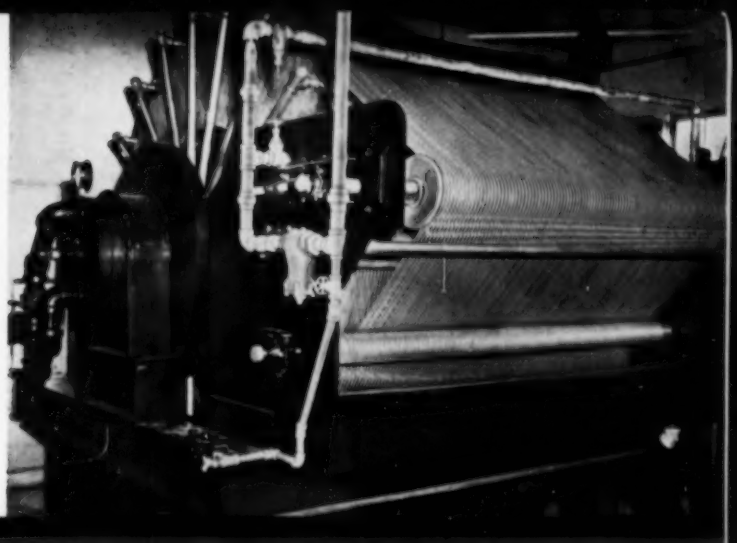
A COILFILTER installed in a glass-enclosed drying bed, which it replaced. 100 Sq. Ft. unit at Mt. Pony, Penna. Engineers—Gilbert Associates.

ING
IT FILTER MEDIA
IT OUTPUT
PERATING COST



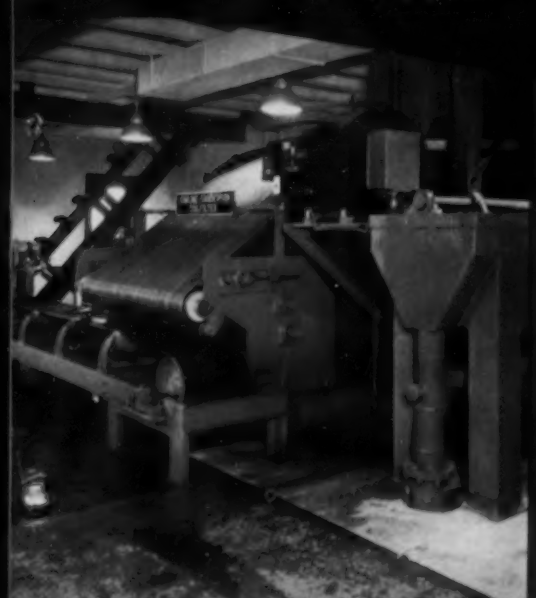
The first COILFILTER unit installed in a municipal sewage treatment plant. A 150 Sq. Ft. COILFILTER at Liberty, N. Y., 1949. Engineers—Olney Borden and W. A. Nordenberg.

COILFILTER unit at Coudersport, Penna. 100 Sq. Ft. unit replacing two 100 Sq. Ft. cloth-type filters. Engineers—Albright & Friel.

The first Komline-Sanderson COILFILTER for dewatering sewage sludge was installed at Liberty, New York, in 1949, the pioneer unit of what has come to be, in just five years, the most widely specified and accepted sewage sludge vacuum filter.

Since 1949, each succeeding year has seen greatly increased use of COILFILTERS. In 1954 more COILFILTERS were purchased in this field than all other vacuum filters combined, proof indeed of product performance.

150 Sq. Ft. curb-mounted COILFILTER at East Providence, R. I. Engineers—C. A. Maguire & Assoc.



COILFILTER INSTALLATIONS

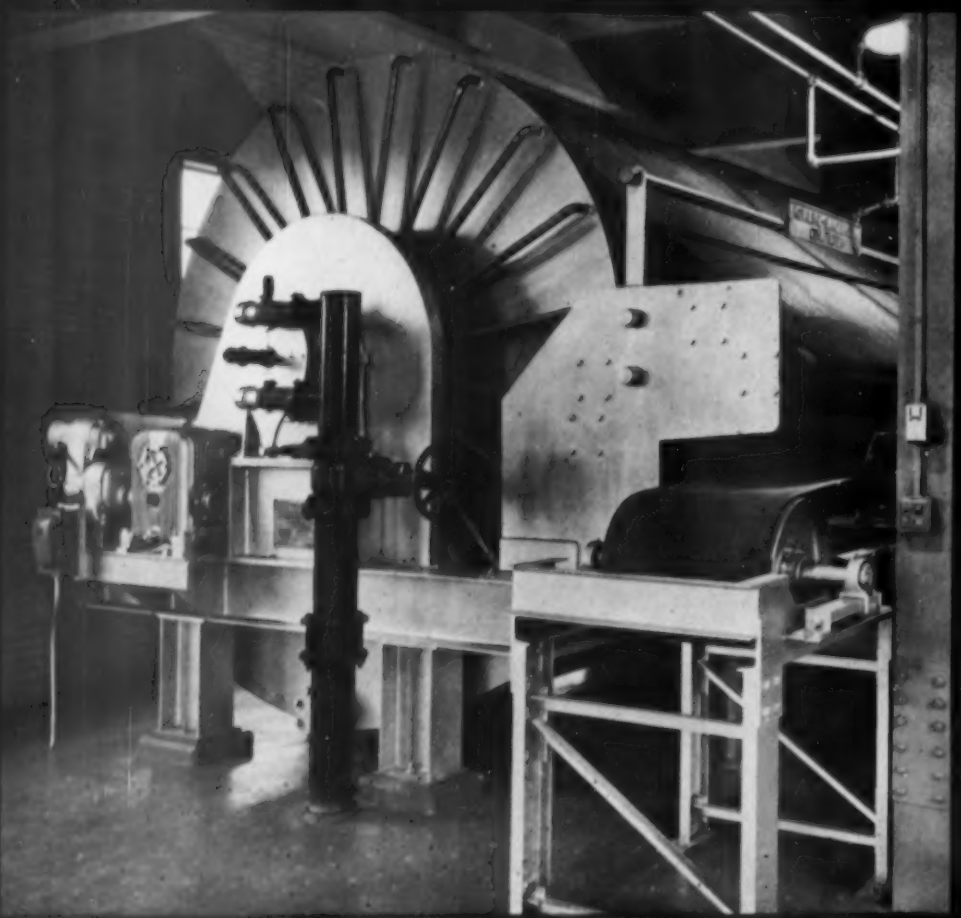
Sewage Treatment Plants—1949-1954

Year Purchased	Plant	No. of Units
*1949	Liberty, N. Y.	1
1950	Glen Cove, N. Y.	1
1950	Gloucester City, N. J.	2
1950	Saddle River, N. J.	2
1950	Monticello, N. Y.	1
1951	Wyoming Valley, Pa.	3
1951	Bethlehem, Pa.	1
1951	Fairfax County, Va.	2
1952	Bethlehem, Pa.	1
1952	Levittown, Pa.	1
1952	York, Pa.	2
1952	Hopewell, N. J.	2
1952	Rockland, New York, N. Y.	2
1952	Bixby, Penna.	2
1952	Bedford, Ohio	1
1952	Woodbridge, N. J.	2
*1953	Perth Amboy, N. J.	1
1953	Williamsport, Pa. (Central Plant)	2
1953	Williamsport, Pa. (West Plant)	2
1953	Bayonne, N. J.	2
1953	Lima, Ohio	1
*1953	Coudersport, Pa.	1
*1953	St. Charles, Ill.	1
1953	Shenandoah Heights, Montgomery County, Ohio	1
1953	Dallas, Ohio	1
1953	Kalamazoo, Mich.	1
1953	Mt. Penn, Pa.	1
1953	Elkton, Florida	4
1954	Williamson, Mich.	1
1954	Norristown, Pa.	1
1954	Ashtabula, Ohio	2
1954	Merrill, Wis.	1
1954	Groton, Conn.	1
1954	New Rochelle, N. Y.	1
1954	Speedway, Ind.	1
1954	Kewaunee, Wis.	1
1954	Erie, Pa.	2
1954	Coral Gables, Fla.	1
1954	Steubenville, Ohio	1
1954	Dayton, Ohio	2
1954	Kokomo, Indiana	1
1954	Union City, Tenn.	1
1954	Lorain, Ohio	1
1954	Perrysville, Ohio	1
1954	Delphos, Ohio	1
1954	Marietta, Ohio	1
1954	Jersey City, N. J.	4
1954	Alexandria, Va.	2
1954	Hatboro, Pa.	1
1954	Chicago Heights, Ill.	2
1954	Frankfort, Ind.	1
1954	Corpus Christi, Tex. (OSO Plant)	1
1954	Charleston, W. Va.	2

*Replaced Cloth-type Filters

1952 photograph of Komline-Sanderson plant at Peapack, New Jersey.

1954 photograph of the greatly enlarged plant. Another expansion is now being planned.



Two 300 Kw. Pt. COMPUTER units installed at the York, Penna., sewage treatment plant. Engineers-Allbright & Friel.

KOMLINE-SANDERSON ENGINEERING CORPORATION

Peapack, New Jersey

TABLE 1

Principal Characteristics of the Sludges Used in the Experiments

Source of Sludge		New Haven	Torrington	West Haven	Waterbury
Type of Sludge		Digested; $FeCl_3$ and lime; vacuum filtered	Digested; air dried on sand beds	Elutriated, digested; $FeCl_3$; vacuum filtered	Flash-dried, raw
Moisture content as sampled:					
(As delivered)	A.D. %	72	69	71	8.5
(Water-free basis)	W.F. %	257	223	245	9.3
pH as used		7.5	5.6	6.0[1]	7.9
Loss-on-ignition	W.F. %	41.7	43.2[2]	56.4	71.0
Total nitrogen	A.D. %	1.50	2.29	2.48	1.55
Organic carbon	A.D. %	28.8	27.8	35.9	50.4
C-N ratio		19.2	12.1	14.5	32.5
Calculated organic carbon[3]		23.2	24.0	31.3	38.6
Calculated C/N		15.5	10.5	12.6	24.9
Total phosphorus	A.D. %	0.67	0.58	0.60	0.50
Total potassium		VL[4]	VL	VL	VL
Total calcium	A.D. %	4.33	1.13	1.88	3.60
Total magnesium	A.D. %	0.26	0.18	0.14	0.17
Cation exchange capacity	A.D. me/100 gm.	25	27	32	23
Weight per cu yd as delivered	lbs.	1085	1450	1210[5]	428
Weight per cu yd waterfree	lbs.	300	627	350[5]	404
Presence of industrial waste		Some textile dyes	Wool scouring and metal plating wastes	No appreciable amount	Large amounts of metal plating wastes

[1]Subsequent samples tested 5.2 and 4.5
[2]Av. of 6 samples which ranged from 29 to 51%
[3]Loss-on-ignition 1.8 = organic C. (A simple approximate method used in New Zealand for estimating the organic carbon content of sludges).
[4]VL = very low
[5]Estimated

Now every experienced gardener knows that neither spinach nor beets thrive on strongly acid soils. But we found that the plants growing on the sludge treated acid soils were even poorer than those on the check soils, likewise acid,* which suggests a toxic factor in the sludge. This idea was further supported by the fact that freshly applied sludge seemed to interfere with seed germination. During the early stages of growth in the greenhouse one could readily pick out the sludge treatments by the appearance of the seedlings (fewer and smaller), and in a test with lettuce seed[2], germination was reduced to as low as two percent as compared with 60 per cent for the checks. Further, when blotting papers used in germination tests were saturated with infusions from water extracts of sludges, seed germination was seriously inhibited[2]. In both cases, Torrington sludge had less effect than did New Haven sludge.

Another example of variable response of plants to sludge treatment comes from our field plot experiment on Merrimac sandy loam in Peoples Forest Nursery, Barkhamsted, Connecticut. Here, Torrington sludge was applied to small plots at the rate of 50 and 150 cu. yds. per acre, along with fertilizers but without lime. (Nursery soils should be acid.) The plots were seeded to four forest tree species—Norway spruce, white spruce, red pine and white pine. This was in the fall of 1951.

Observations a year later showed no effect from the 50 cu. yds. rate. The righ rate, however, tended to cause somewhat thinner stands and slightly smaller seedlings of the spruces and white pine; and in the case of red pine, conspicuous red tipping of the needles and a poor stand generally.

Before exploring the toxicity angle, two more observations should be made. Firstly, in all our experiments, grasses and small grains have responded well to sludge, whether the soils were acid or neutral. (No data were obtained on yields of thrashed grain but this is not a practical problem in Connecticut, for little or no grain is harvested). Where sludge was applied in December to a rye cover crop on field plots, the plants were larger and a deeper green and the stand thicker, at the time of spring plowing, than were the plants without sludge. Lawn grass top-dressed with screened New Haven sludge increased in growth and in depth of color. Thus it is obvious that crops differ in their response to sludge treatment.

The second observation is that our studies have shown no evidence of root injury of lettuce and radish seedlings[2] caused or aggravated by sludge treatment.

Minor Element Toxicity

The forementioned unfavorable effects of sludge led us to have the sludges analyzed and later to make further germination tests. These analyses showed appreciable quantities of boron, copper and zinc, the latter reaching a concentration of over 5000 ppm (parts per million) in two instances. Table 2 shows the principal minor element content and the pH of several typical Connecticut sludges from municipal plants, and the averages from State institutions. For comparison, data are included for some organic materials commonly applied to soil. It is readily seen that all the sludges (including Milorganite) are much higher in boron, copper and zinc than are the other organics. It is also evident that municipal sludges contain larger amounts of these constituents than do the institutional sludges, although the differences are much smaller than had been anticipated.

Analysis of ammonium acetate extract of the soils to which sludge had been applied showed some increase in available copper and about double the concentration of available zinc. Then we analyzed the plants—spinach, beets and oats—and found that all those growing in sludge-treated soil contained a little more copper and a lot more zinc, the latter ranging

TABLE 2

Minor Element Content[1] and pH of Connecticut Sewage Sludges and of Other Organic Materials

Source	B ppm	Cu ppm	Mn ppm	Zn ppm	pH
Bristol	210	540	210	3570	6.06
Hartford	360	830	280	3200	5.40
New Haven	190	830	190	3280	7.50
Torrington	160	1025	135	3170	5.70
West Haven	225	465	105	2200	6.16
Waterbury	265	760	170	2540	7.90
Av. of Municipal plants[2]	211	758	172	3205	6.12
Av. of State Institutions[3]	148	535	110	2433	5.82
Milorganite	1080[4]	500	170	2000	5.05
Peat Moss	31	24	30	Trace	4.00
Cow Manure	38	61	150	210	
Peat Soil	50	5	40	Trace	5.50
Forest litter (hardwoods)	40	54	2800	150	4.50

[1]Determined on the spectrograph by W. T. Mathis
[2]25-31 samples from 13 plants
[3]6 samples from 5 plants
[4]This high value is open to question

*Experiments by J. P. Hollis, formerly of the Dept. of Plant Pathology.

TABLE 3

Approximate Amounts of Boron, Copper, Manganese and Zinc Applied in Sewage Sludge and the Amounts Usually Recommended for Deficient Soils

Average concentration in sludge		Approximate amount applied in 10 tons[1] of dried sludge			Usual recommendation for deficient soils. Salt equivalent
Element	ppm	Elements lb.	Salt equivalent lbs.		lbs. per acre
Boron	210	4.2	37	Borax	5-30, occa. 100
Copper	760	15.2	60	Copper sulfate	20-200
Manganese	170	3.4	14	Manganese sulfate	25-60
Zinc	3200	64.0	281	Zinc sulfate	20-40, occa. 200

[1]10 tons per acre of dried sludge is equivalent to about 33 tons of moist sludge or 52 cu. yds. (Torrington sludge, 28 ± cu. yds.)

from 300 to 1200 per cent increase. Boron was not affected appreciably. Recently, an analysis of tomato plants growing on a sludge dump in South Manchester, Connecticut, showed the plants to contain five times as much zinc and twice as much copper as plants not in contact with sludge. (The tomato plant is remarkably tolerant of these elements.)

As a further check on toxicity of copper and zinc, varying amounts of copper sulfate were applied to soil in small flower pots, one series being kept acid and the other treated with lime; and a similar test was made with zinc sulfate. The results on the acid soil, showed retardation of growth, and also injury characterized by yellowish leaves of spinach and red to yellowish-red leaves of beets—the same as observed from *sludge* treatment in acid soil. Of the two metals, copper seemed to develop the more characteristic symptoms, but both were equally toxic.

One more remark on minor element toxicity should be made at this point. Considering the amounts of these metals applied in the sludge treatments, it is not surprising that injury occurred. Table 3 shows the estimated amounts of boron, copper, manganese and zinc applied in 10 tons of average sludge, based on our analyses. Of the four, zinc was by far the highest, being in excess of a safe application, especially when larger amounts of sludge were used.

However, not all of the zinc in sludge is immediately available to plants, even in acid soils. Further, the buffering effect of organic matter tends to reduce the amount of injury. Thus a given amount of a soluble toxic substance is less injurious in the presence of appreciable amounts of organic matter.

Source of Minor Elements

Now for the $64 question, "Where do these minor elements come from?" The answer is simple where industrial wastes are dumped into the sewer system, but as our analyses show that sludges free of such wastes also contain rather high amounts, it is necessary to look for other sources. Copper, brass and galvanized piping undoubtedly contribute some copper and zinc, and wherever these metals form insoluble compounds with phosphorous or lime they would appear in the sludge.

There are indications, however, that appreciable amounts of these minor elements come from food stuffs. Bertrand and Benzon[3] reported zinc in fresh material ranging from less than one ppm in peaches, plums and melons to 50 ppm in legumes. Hegsted et al[4] reporting data from others, show that ordinary foods contain variable amounts of zinc, ranging up to 145 ppm on a dry basis. Yeast, mushrooms and seafoods are high, and oysters may contain as much as 2300 ppm. The daily intake of zinc in a normal diet averages about 10 mg per day per person, but it would be possible to eat a meal of selected foods which would supply 225 to 275 mg of zinc.

The important fact is that practically all of the zinc ingested is excreted, of which over 90 per cent is in the feces.

Germination Experiments

To check further on sludge retardation of germination, several experiments[5] with lettuce seed were run in petri dishes in 1952 using Hartford loamy sand treated with four different sludges at rates of 16, 48, 144 and 240 cu. yds. per acre with and without lime. Also additional germination readings were obtained in existing pot cultures in the greenhouse on lettuce, spinach, oats and beans. Space permits only a brief summarization of the results.

Strangely enough, Torrington sludge favored germination in some cases, particularly where the sludge had been piled out of doors for about a year. Sludge piled only a month tended to delay germination when applied at the higher rates. All of the other sludges—New Haven, West Haven, and Waterbury—generally retarded germination to a degree ranging from 3 to 10 days in the petri dish tests, and 2 to 5 days in the pot cultures, although there were some instances of no delay. Generally speaking, germination was delayed rather than inhibited.

Delayed germination has not been a problem in the outdoor experiments. Perhaps it did not occur, or perhaps it merely escaped our attention, but obviously the matter needs further investigation under field conditions. So far we have not learned what it is in sludge that affects germination.

Incidentally it is interesting to note the effects of the several sludges on soil reaction. Increasing the rate of application from 16 to 240 cu. yds. per acre (without lime) had almost no effect in the case of Torrington and West Haven sludges, but raised the pH by 2 to 2.5 units in the case of New Haven and Waterbury sludges.

Plant Growth Studies

Once the detrimental effect of acidity in sludge-treated soils was recognized our experiments were modified accordingly. In one case the treatments of the Cheshire loam soil were changed to provide a range in acidity, and the cropping to spinach and beets was continued. Although the sludge-treated *spinach* plants were favored by liming, they did not grow as well as did those without sludge. On the other hand, *beet* yields were higher with sludge whenever the pH was 6.4 or higher.

In another experiment, Torrington and West Haven sludges were applied to Hartford loamy sand at rates of 65, 130 and 260 cu. yds. per acre (approximately ½-, 1-, and 2-inch layers, resp.) One set was maintained in an acid condition (pH 4.8-5.3), and cropped alternately to oats and beans. The other set was limed, then cropped alternately to spinach and beets.

Yield data of the acid series show that growth of the first crop of oats and of the succeeding bean crop was markedly increased by applying sludge

[3]Bertrand, G. and Benzon, B. The control of zinc in the principal foods of vegetable origin. Bul. Soc. Sci. Hyg. Aliment. 16:457-463, 1928, and Ann. inst. Pasteur 43:386-393, 1929. (Abs. seen in Bib. Minor Elements, 4th Ed. Vol. I:938. 1948).

[4]Hegsted, D. Mark, McKibbin, John M., and Drinker, Cecil K. The biological, hygenic and medical properties of zinc and zinc compounds. Supplement No. 179 to the Public Health Reports, U.S. Public Health Service, Washington, D. C. 1945.

[5]Frances Meyer, Plant Path. Dept., assisted in this work.

up to the 130 cu. yd. rate, with a rapid falling off at the 260 cu. yd. rate. But the second oat crop was only slightly benefited by the low and medium rates of applied West Haven sludge, and was actually decreased by the Torrington sludge. No abnormalities occurred in the appearance of the oat plants at the high rate, but the bean plants receiving Torrington sludge developed a yellow mottling between the veins of the leaves, and those getting West Haven sludge showed a dying of the tissue (necrosis) of the same areas.

In the limed series the first crop of spinach was not benefited by West Haven sludge and was actually reduced by Torrington sludge. Tests showed that insufficient lime had been used, hence additional lime was applied as needed prior to seeding the succeeding beet and spinach crops. In the third crop, spinach, West Haven sludge caused marked increases, especially at the 260 cu. yd. rate, while Torrington sludge had exactly the opposite effect.

Again pH Value Proves Important

Let's look at the pH of the soil after each harvest, as shown in Table 4.

Inspection of these data helps explain the difference in response of the two spinach crops to West Haven sludge. When the pH was brought well above 6, increases occurred. In the case of Torrington sludge, the pH remained about constant (over pH 6 in all cases), yet growth of the plants was reduced by the sludge. Probably the presence of industrial wastes in Torrington sludge makes the difference and thus precludes its use for spinach.

Soil Improvement

Our work has shown that grasses and small grains usually respond favorably to sludge applications, and that most other crops may likewise be benefited under the proper conditions. Although not all the factors responsible for these increases in production are shown, it is certain that available nitrogen released by the sludge, and improvement in the physical condition of the soil are the chief causes.

The relative contribution of each is difficult to assess but soil studies readily show the effect of sludge on soil properties. Some of these are given in Table 5.

Increases in organic matter, in total nitrogen and in soil aggregation were substantial and definitely significant. Few other amendments are known which are as effective as sludge in this respect. Note that Torrington sludge was more effective than either New Haven or West Haven sludge in increasing organic matter and nitrogen but less effective in increasing soil aggregation, even though all three sludges were applied in equal quantities by volume. Possibly the more fibrous character of the latter two sludges is responsible for their greater effectiveness in aggregating soil particles. A well-aggregated soil means better aeration, greater ease of root penetration and increased rate of water infiltration. Therefore the beneficial effects are very significant to agriculture.

Smaller but nevertheless important increases were found (Table 5) with respect to field moisture capacity, cation exchange capacity[a], and noncapillary porosity; and there were decreases in bulk density, i.e. weight per cubic foot.

It should be pointed out that greatest benefits physically from organic matter applications usually occur relatively soon after application, i.e. within the first 12 to 18 months. After that period the favorable effects gradually diminish, which means that sludge applications need to be made probably every three to five years.

Also our work indicates that greater benefits are likely to accrue to lighter soils such as sandy loams than to loams and silt loams. Although we have not worked with clay loams and clays, it is presumed that they would be appreciably benefited by sludge, chiefly in making them more porous and better aerated.

There is another use for sludge—making topsoil out of natural subsoil—a practical solution to topsoil loss where it has been removed by erosion or by sale of balled plants in commercial nurseries. The New York City Park Department employs digested sewage sludge in the preparation of artificial topsoil for use in the city parks.

[a]The ability of a soil to hold and exchange bases, chiefly calcium, potassium and magnesium.

Table 4
Soil pH Values After Harvesting Crops

Succeeding crops	Check	West Haven Sludge			Torrington Sludge		
Cu. yd. sludge per acre	0	65	130	260	65	130	260
1. After spinach	5.9	5.6	5.5	5.4	6.1	6.2	6.2
2. After beets	6.7	6.6	6.3	6.1	6.5	6.4	6.5
3. After spinach	6.2	6.0	6.7	6.7	6.4	6.4	6.4

Table 5
Effect of Sludge Applications on Several Properties of Cheshire Loam
(Rates are expressed in cu. yards per acre)

		Check (No Sludge)	New Haven Sludge		Torrington Sludge	
			88	176	88	176
Field moisture capacity	%	24.4	25.1	25.8	27.2	29.9
	Relative	100	103	106	112	123
Non-capillary porosity	%	25.3	27.7	28.5	30.0	27.6
	Relative	100	109	112	119	109
Cation exchange capacity	me/100g	11.15	11.99	12.35	11.80	12.12
	Relative	100	107	111	106	109
Bulk density (water = 1.0)		1.13	1.09	1.07	11.05	0.99
	Relative	100	96.2	95	92.5	87.5

Conclusions

From these findings it is concluded that digested sewage sludge as produced in Connecticut treatment plants is markedly beneficial to our soils and, when used under proper conditions, it improves crop yields. Our research has shown that: (a) growth of small grains and grasses was generally increased irrespective of the soil pH; (b) crops like beets and spinach are benefited only where the soil is adequately limed (pH 6.5 or higher); (c) coniferous nursery stock is probably benefited by moderate rates of sludge (50 cu. yds.) provided the soil acidity is maintained at about pH 5.3—5.8.

On strongly acid soils, sludge applied at rates approximating 50 cu. yds. per acre was found to be deleterious to most agricultural crops (except grasses and small grains) as the result of minor element toxicity. Very high applications, approaching 150-250 cu. yds., may be disastrous unless the soil is well limed.

Some sludges tend to delay germination, particularly at the higher rates of application, and especially where the sludge is fresh from the treatment plant. In field practice moderate applications applied some months before seeding would presumably not create this problem.

Addition of Garbage to Sewage

By T. R. HASELTINE
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THERE are four different ways by which garbage has been added to sewage. The oldest and most common method is the "lift the seat, dump and flush method," which has probably been in use ever since sewers and commodes were invented. That this method is extremely common is evident to anyone who examines the screenings or scum on a primary settling tank at almost any sewage treatment plant. The method is not scientific, however, and therefore we will dispense with any further discussion of the procedure.

Methods of Adding Garbage to Sewage

The three important methods of adding garbage to sewage are by central grinding stations with discharge to sewers, grinders at sewage plants with discharge to sludge digesters, and home grinders.

The first trial of central grinding stations was at Lebanon, Pa. in 1923. Since then such stations have been used at Baltimore, Md., Indianapolis, Ind., St. Louis, Mo., Gary, Ind., Lansing, Mich., Durham, N.C., Marion, Ind., and perhaps other places. The grinding stations have been located on trunk sewers either immediately ahead of the sewage treatment plant, or at more central locations throughout the city.

When the grinder is located at the sewage plant it has been found advantageous to discharge the ground material directly to sludge digesters, thus avoiding any effect on most of the other sewage treatment units. Both the advantages and disadvantages of this method will be discussed more fully later in this paper.

While central grinding stations may be of only theoretical interest to the operators of most sewage treatment plants, the last named method, namely domestic household garbage grinders, should be of interest to every sewage plant operator. The City of Butler, Pa., has an ordinance which prohibits the installations of these household grinders and I am told that Fond du Lac, Wis., is the only city west of Butler that has a similar ordinance. I mention this to demonstrate the apparent widespread acceptance of these units.

Central grinding stations will not eliminate the individual garbage cans or the disagreeable and unsightly parade of garbage collection. On the other hand domestic grinders will completely eliminate much of that odorous and fly beridden nuisance.

At one time human wastes were collected daily in wagons and hauled to points of disposal. Today, no civilized country would countenance such a procedure. Perhaps at some far distant time the attitude of the public to garbage collection will be the same as is the present day public's attitude to the collection of human wastes. When that time comes, domestic garbage grinders will no doubt be as universally used as is water carriage of human wastes today. However, I believe that time to be in such a far distant future that present day designers or operators need not be concerned about the use of garbage grinders in more than half of the homes.

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Central Grinding Stations

The grinders used at central grinding stations are of two types, either the hammermill type, as manufactured by the Jeffrey Manufacturing Co. and Gruender, or the rotary shear type, as manufactured by Mitts and Merrill. Power consumption varies with the fineness of the grind. Early experiments with some of these units only attempted to grind the garbage so it would pass a ¾-in. mesh screen. However, experience indicated that a finer grind was desirable and now, so far as the writer knows, present day units attempt to grind all material so it will pass a ¼-in. mesh screen. Power consumption ranges from 4 to 5 kilowatt hours per ton of garbage ground. Jeffrey makes five different sizes of units ranging from 2½ to 30 tons per hour in capacity. The smallest unit is powered by a 10 horsepower motor and the largest unit by a 100 horsepower motor. The smallest Gruender grinder has a capacity of 6 tons per hour and is powered by a 30 horsepower motor. The Mitts and Merrill grinders range in capacity from 6 to 24 tons per hour and have motor sizes ranging from 40 to 150 horsepower. All three makes have provisions for segregating tramp metal. However, tin cans are not included in this category, and are cut up with the wet garbage in event they enter the units. Grinders of the hammermill type have difficulty in handling such material as corn husks or poultry feathers.

Water is added to assist in flushing the ground materials through the machine, as is the case of the domestic grinders. Water consumption ranges from 500 to 700 gallons per ton of garbage ground, depending upon whether the units are operating at below capacity, or their rated output.

C. E. Keefer of Baltimore, Md. states that the noise created by central grinding stations can be heard for distances of 400 to 500 feet, but concludes that the odor nuisance from such stations is much less than that from either incineration or garbage reduction.

Domestic Grinders

Although the General Electric Co. "Disposall" is the best known household garbage grinder, there are more than a dozen different manufacturers of kitchen garbage grinders and at least four manufacturers of units for restaurants and hotels. Several of the household type manufactures are licensees of General Electric. Specifications for one of these household units supplied by one of the manufacturers include the following:

"The food waste shredder shall discharge shredded wastes at a reasonably uniform rate, in a fluid form, which shall flow readily through an approved trap, drain line or soil line in a manner which will prevent clogging or stoppage of drain line. The food waste shredder shall shred food waste to a uniform size to meet the following requirements: 100 per cent shall pass ½-in. screen, at least 90 per cent shall pass a ¼-in. screen, not over 5 per cent shall pass a No. 40 sieve. Screens shall be the U. S. Standard and weight shall be taken on a dry basis."

The units handle about one pound per minute of ordinary household garbage. During grinding, water is added at the rate of 1½ to 2½ gpm.

It has been suggested that as home grinders develop in popularity, ordinances prohibiting their use will be as difficult to enforce as are our present ordinances prohibiting the introduction of roof drainage into sanitary sewers. At present, these domestic units are still too high priced to be installed in any but the more expensive homes. However, many people expect that their use will some day become as widespread as our electric refrigerators today.

In the May, 1949, issue of *Water & Sewage Works*, Mark Owen traces the development of radios, refrigerators, automobiles and similar units and draws a comparison between those units and domestic grinders. It is his estimate that by 1965 domestic grinders will be used in approximately 45 per cent of the homes, and that from then on their usage will increase until they will be found in from 50 to 60 per cent of the homes. It should be noted, however, that radios, electric refrigerators and automobiles are still not used in all homes, and therefore, unless home grinder use is made compulsory, there is no reason to expect that household grinders will ever be universally used.

Quantity and Character of Garbage

It must be borne in mind that only wet, or green, garbage can be added to sewage. It should preferably be unwrapped, relatively free from paper, and fit to feed hogs. Ramsey states that in an average city wet garbage constitutes 65 per cent of the total tonnage of refuse. At Los Angeles, where there are little or no ashes, and combustible refuse is not collected, wet garbage constitutes 77 per cent of the total tonnage of refuse collected. Thus it appears that we would still have dumps and periodical visits of the rubbish man, even though domestic garbage grinders were universally used.

Before considering the effect of the admission of ground garbage to sewers or sewage treatment plants, it is necessary to have some idea of the amount of such garbage that might be added. A rather extensive review of the literature indicates that the average annual production of green garbage ranges from about 0.4 to 0.8 lb. per capita per day. Some of this variation may be due to variations in moisture content, which has been variously reported from 60 to 98 per cent. For the purposes of this discussion I have assumed a per capita green garbage production of 0.6 lb. per day, containing 75 per cent moisture.

The per capita production of garbage is subject to greater seasonal variations than is the per capita production of sewage solids. For example, at Columbus, Ohio, where the average production of garbage was 0.68 lb. per capita per day, over a 12 year period, the peak for a 30 day period during that time was 1.37 lbs. Maximum production occurs during the summer when green vegetables are most plentiful and usually is at a minimum during the month of February.

The literature contains numerous analyses of garbage, many of which do not agree. This is not surprising; in fact,

there is no more reason to expect various analyses of garbage to agree than there would be to expect various analyses of sewage or sewage sludge to agree. In the accompanying table is presented more or less typical analyses of all three substances:

Comparison of Character of Garbage with Sewage and Sludge

	Pounds Per Capita Per Day		
	Ground Garbage	Sewage	Primary Sludge
Total Solids	0.15	0.55	0.12
Total Volatile Solids	0.13	0.32	0.08
Suspended Matter	0.10	0.20	.....
5 Day B.O.D.	0.08	0.17	.....
Fats and Greases	0.03	0.05	0.03
Nitrogen	0.002	0.04	0.003
Moisture	0.45	.....	2.28
Total (Moisture + Total Solids)	0.60		2.40

Even a casual inspection of that table must make it evident that the universal admission of ground garbage to sewage is bound to materially increase the burden on sewage treatment plants or receiving streams. The table is somewhat misleading in that the figures for ground garbage are based upon the assumption that the garbage is ground without the addition of water, while as above stated, this is not the case, either for domestic grinders or for central grinding stations. Water consumption with domestic grinders ranges between 1 and 2 gallons per capita per day. The water consumption of central grinding stations averages about the same, if it is assumed that 0.6 of a pound of green garbage per capita is produced and that water consumption ranges from 500 to 700 gallons per ton of garbage ground. This water dilutes the garbage so that instead of having an initial solids content of 25 per cent as assumed in the accompanying table, it would have a solid content of only about 7 per cent.

Effect of Garbage on Sewage and Sewers

The figures in the table indicate that if all garbage from a community were ground and added to the sewage, that the suspended matter and B.O.D. of the raw sewage would be increased approximately 50 per cent. Since domestic grinders will not be located in all of the homes, the increase resulting from their use will be proportionately less. However, the information previously given on water usage indicates that even were all garbage of a community to be ground, either by domestic grinders or in central grinding stations, the quantity of sewage would be increased only about 1 or 2 per cent, (based upon an assumed sewage flow of 100 gallons per capita per day). Thus it is evident that so far as size or capacity of sewers is concerned, the grinding of garbage and deposition into those sewers will have no effect.

Experience with domestic grinders has shown that the admission of finely ground garbage to house plumbing does not cause clogging in them; in fact, there is a tendency for the garbage to keep the inside of the pipes clean.

Normal domestic sewage and most industrial wastes are extremely dilute. For example, a flow of 100 gallons per capita, containing 0.2 of a pound of suspended matter would have a suspended solids content of 250 ppm. Even if all garbage were ground and added to the sewers, the suspended solids content would only be about 360 ppm. In the design of sewage structures, engineers apply the same laws of hydraulics to the flow of sewage as are applied to the flow of water. Water which carries suspended matter continues to flow as water until the concentration of suspended particles become so great that they touch one another in the fluid.

Sewage is so dilute to start with that it does not seem possible that a 50 per cent increase in suspended solids would cause any more deposition than occurs in normal sewage. Therefore, if a sewer system is free from deposits before the admission of garbage, it is reasonable to expect that it will remain so after the addition of ground garbage. However, if troubles are now experienced with deposition of sewage solids in certain portions of a sewer system, the addition of ground garbage may be expected to increase the amount of deposition at those particular localities.

Furthermore, inasmuch as garbage is higher in volatile solids than is sewage, the volatile content of those deposits would be increased, thus increasing the putrescibility and the likelihood of creating obnoxious odors. The necessity for flushing sewer systems would be increased and, in event the frequency of such flushings was not stepped up, sewage reaching the treatment plant would be more septic than it had been in the past. These troubles might warrant the exclusion of ground garbage from sewage collection systems. The blame, however, should not be placed on garbage grinders or garbage, but upon the inherent faults in the design or construction of the sewage collection system.

Even well designed sewer systems are troubled with deposition of solids at the upper ends of laterals where the volume of sewage is too small to maintain adequate depths of flow and hence solids become stranded along the pipe. It is to be expected that if domestic grinders are installed in homes tributary to the upper ends of these lateral sewers, that such difficulties will be increased. Flushing would be the only remedy.

After considering all of these factors, it seems reasonable to conclude that there should be no objections to the admission of properly ground garbage to a well designed and constructed separate sewer system. Such may not be the case with a combined system. Most combined systems are designed with storm water overflows which come into operation whenever the total flow exceeds 2 to 3 times the peak dry weather flow. The theory being that the overflow at that time is so low in suspended solids and B.O.D. that it has no deleterious effect upon the receiving stream which presumably is also a flood stage. If, however, all the garbage of the community has been ground and added to this sewage, then its B.O.D. and suspended solids content will be increased 50 per cent, and hence the B.O.D. and suspended solids content of the storm overflow would be correspondingly increased. Whether or not such an increase would cause objectionable conditions in the receiving stream is a matter for individual study in each locality.

Effect of Garbage on Grit

Now let us consider the possible effect of the addition of ground garbage to sewers upon the various sewage treatment plant structures. First let us consider grit chambers. Carpenter, et al, states, "that where the municipality collects the refuse, it will be difficult to educate householders to separate the garbage from foreign materials. In cities where garbage is disposed of by feeding to hogs or reduction, large amounts of metal and glass are found in the garbage. Unless such materials are removed before the garbage is ground, grit chambers in existing plants may have to be extended."

At Indianapolis, where all garbage was ground and discharged into the sewage for seven months, the garbage was hand picked for tin cans, heavy bones and large pieces of metal. The picked material constituted 3.1 lb. of bones and 3.4 lb. of metal per ton of green garbage. Despite this hand picking, the garbage produced 38.2 lb. of grit (containing 28 per cent water) per ton of green garbage. This constituted an average increase of 23 per cent in grit collections for the Indianapolis plant. Green garbage collections at Indianapolis amount to only 0.43 lb. per capita per day. In cities where the quantity of garbage is higher, the amount of grit will also be higher. On the basis of 0.6 of a lb. of green garbage per capita, the increase in grit might have been 35 instead of 23 per cent.

At Finley, Ohio, where a central grinding station is used, garbage additions are made at the rate of 1.1 ton per million gallons of sewage. Prior to operation of the grinding station, grit collection averaged 1.5 cu. ft. per mil. gal. of sewage, while since the operation of the grinding station, they have averaged 2.7 cu. ft., thus indicating an 80 per cent increase in amount of grit.

Garbage grit is largely bones, egg shells, etc. Its volatile content is higher than that of good grit and frequently it is much more offensive. Experience at Indianapolis showed that by grinding to pass ¼-in. mesh instead of ¾-in. mesh that the offensiveness of the grit could be materially reduced. The use of grit washers will probably be found more necessary if central grinding stations are installed on trunk sewers.

It is to be expected that less grit will result from the grinding of garbage in domestic grinders than would be the case where central grinding stations are used. This statement is based upon the observation that it is just human nature to take better care of your own garbage grinder unit that you have paid for out of your hard earned money, than it is to worry about including large bones or tin cans in so-called green garbage which is to be delivered to the city's grinder.

Effect of Garbage on Sedimentation

The addition of ground garbage to sewage may affect the performance of primary settling tanks in three different ways: (a) the amount of scum produced, (b) tank efficiencies and quality of effluent, and (c) the kind and amount of sludge collected.

Experience has shown that the addition of ground garbage definitely increases the amount of scum forming on the top of primary tanks. However, the more uniform the additions of garbage and the finer its grinding, the less serious becomes the scum problem. It is generally recognized that all primary settling tanks should be provided with mechanical skimming devices. If this is done and garbage

additions are made at the uniform rate, or as uniform as might practically be obtained, it is not to be expected that the increase in scum formation will be serious. Screening of settled sewage through ¼-in. mesh screen might be advisable to prevent floating solids causing trouble with secondary treatment devices. This scheme is now used at a number of sewage plants, particularly those having comminuters or bar screenings shredders, and causes no undue difficulty in operating problems.

As regards settling tank efficiencies, all investigators seem to agree that the addition of finely ground garbage increases the percentage removals of both suspended solids and B.O.D. by plain sedimentation, but there the similarity in published results ends. One investigator reports that these percentage increases in removals are so great that they completely offset the increase in solids and B.O.D. of the raw sewage, and therefore the settling tank effluent actually has as low, or a lower, B.O.D. content than it did prior to the introduction of garbage. Another investigator, however, reports that the addition of ground garbage to sewage may increase the B.O.D. of the settled sewage as much as 100 per cent. Most of these investigations were made on laboratory or small pilot plant scale. Results from existing sewage treatment plants are difficult to interpret because frequently the addition of ground garbage was not the only change made at the sewage treatment plant. Frequently central stations were constructed at the same time that secondary treatment processes were installed and thus return of secondary sludge or changes in the character of digester supernatant being returned to primary tanks might well account for some of the changes observed in the quality of settled sewage.

After reviewing all of the available literature, the writer has come to the conclusion that the addition of ground garbage to sewers ahead of the primary settling tank may result in a 5 to 10 per cent increase in the suspended solids content and a 15 to 30 per cent increase in the B.O.D. of the tank effluent. These figures apply to a municipality where all green garbage is ground. Obviously if domestic garbage grinders are installed in only a few of the homes, the resulting increase will be correspondingly less, and in fact, may be so small that it cannot be observed until such time as those grinders become more universally used.

As regards volume of sludge collected in primary settling tanks, the literature seems to indicate that in general the garbage solids have settling characteristics similar to those of the sewage solids and that therefore the solids content of the primary sludge will be about the same after the addition of ground garbage that it was before. Because of the increase in total solids, however, there will be a corresponding increase in volume of sludge. In fact, as the figures in the table on garbage characteristics would indicate, and as confirmed by several statements of various investigators, it appears reasonable to expect that the volume of sludge would be increased 100 per cent as a result of ground garbage additions from the entire community. Since the garbage solids are higher in volatile matter than are the sewage solids, the increase in volatile content of the sludge will be even greater, perhaps 150 to 175 per cent.

Effect of Garbage on Chemical Treatment

When garbage is ground much of the matter which was originally in suspension goes into either true solution or colloidal dispersion. The more distant the grinding point above the sewage plant, the greater will be the amount of material dissolved. Rudolfs has found that actually a considerable portion of this dissolved material is in true solution rather than colloidal dispersion and as such is not amenable to chemical coagulation. Therefore, chemical precipitation will not effect a B.O.D. reduction as great on mixtures of sewage and ground garbage as it will on sewage alone.

Rudolfs also found that the addition of ground garbage to sewage increased the amount of chemicals required for coagulation. When iron salts were used as the coagulant, the addition of garbage always increased the iron demand at least 5 to 10 ppm. The importance of pH adjustment with iron appeared more pronounced in sewage garbage mixtures than in sewage alone. Optimum coagulation occurred at a pH of 8.5 to 9. On the other hand, where alum was used as the coagulant, the addition of garbage to the sewage made less difference in the chemical demand. Optimum coagulation was at a lower pH.

Effect of Garbage on Secondary Treatment

In general, grit chambers and primary settling tanks are designed on the basis of sewage volume and since the addition of ground garbage makes very little increase in volume of sewage, little or no change in these structures are required to adopt them to sewage garbage mixtures, even though operating problems such as sludge quantities, grit quantities, or chemical coagulant requirements may be increased by the addition of ground garbage.

Now let us consider secondary or oxidizing methods of sewage treatment. Since the addition of ground garbage increases the B.O.D. of either settled or chemically coagulated sewage, and since these oxidizing treatments are designed partly, at least, on the basis of B.O.D. loading, it seems obvious that secondary treatment structures must be increased if ground garbage is to be added to the sewage. Obviously, the amount of increase is dependent upon the amount of garbage added. The effect of these additions of ground garbage upon the activated sludge process has been reported by a number of investigators. All seem to agree that the oxygen demand resulting from the addition of garbage is just as readily oxidized as is the normal oxygen demand of the settled sewage. They also agree that the addition of ground garbage does not interfere with nitrate production and that, providing aeration periods and air usage are adequate, it has no deleterious effect upon settling or oxidizing characteristics of the activated sludge itself.

Tolman has concluded that the addition of ground garbage to raw sewage would increase the required capacity of aeration tanks for the activated sludge process by 5 per cent, and the quantity of air required by 11 per cent.

Less research has been done on trickling filters. It is generally agreed, however, that the organisms responsible for oxidation on trickling filters are the same as those responsible for oxidation in the activated sludge process. Therefore, it seems logical to believe that mixtures of ground garbage and sewage may be as easily treated on trickling filters of adequate size as mixtures can be treated in suitable activated sludge plants. It is quite possible, however, that floating solids resulting from increased scum formation on primary tanks might cause difficulties with nozzle clogging on trickling filters unless screens are injected between the primary tanks and the filter distributors.

Where only primary treatment is practiced, the receiving stream is actually the secondary treatment or oxidizing unit of the complete sewage disposal system. Obviously, increases in B.O.D. or suspended solids of the settled sewage place a greater burden on the receiving stream. Whether or not it can handle that burden is a problem for local investigation in each case.

Effect of Garbage on Sludge Digestion

Repeated laboratory studies have shown that the organic matter in garbage is digestible regardless of whether such material is digested alone or mixed with sewage sludge. Experiments on the digestion of garbage solids alone indicated that there was a tendency for the formation of acid conditions and that frequently the pH dropped so low that digestion was seriously retarded or inhibited.

Inspection of the table of analyses previously given indicates that nitrogen constitutes only about 1.5 per cent of the volatile matter in garbage, as compared with almost 4 per cent in primary sewage sludge. Quite possibly there is not enough nitrogen in the garbage to maintain the necessary alkalinity for good digestion. In the case of digestion of a garbage-sewage sludge mixture, although the nitrogen to volatile matter ratio is considerably lower than it is in the sewage sludge alone, it is apparently high enough so that little or no difficulty is encountered in maintaining suitable alkalinity and pH for sludge digestion.

Ground garbage has been successfully digested with sewage sludge in ratios varying from 0.3 up to 1.5 parts of dry volatile garbage solids per part of dry volatile sewage sludge solids.

Data indicate that at least 16 cu. ft. of gas may be expected per pound of volatile garbage solids digested. This compares with estimates of 15 to 18 cubic feet per pound of volatile sewage solids digested. As might be expected, the optimum temperature for digestion of sewage garbage mixtures is the same as for the digestion of sewage solids alone. Babbitt had little or no success in digesting garbage sewage mixtures in unheated Imhoff tanks during the winter months, but was quite successful in digesting it in heated separate digestion tanks. Obviously, seeding and mixing of incoming raw sludge with actively digesting material is just as necessary when digesting the mixtures as it is when digesting sewage sludge alone, but again there seems to be considerable difference of opinion as to whether or not mechanical mixing and stirring devices are necessary and if so, which type of device is best suited to the problem.

While there is every reason to believe that garbage may be successfully digested when mixed with sewage or sewage sludge, it does not follow that the addition of garbage to sludge digestion facilities already operating under a heavy load would cause no serious difficulty.

In the operation of sludge digestion tanks, there is no single unit by which the loading on a particular tank can be measured. Loading is a function of both the volume of the raw sludge, and the weight of dry volatile solids introduced into the tank. Obviously more volatile garbage solids will require digestion if the ground garbage is discharged directly to the digester than if it is discharged to the trunk sewer.

Various investigators have reported that when the ground garbage is fed to the sewage, the quantity of garbage reach-

ing the digester will vary from 40 to 75 per cent of the total garbage additions. If we assume this percentage to be 67 per cent, then it is obvious from the foregoing table that the direct addition of ground garbage to the digester would increase the quantity of dry volatile solids to be digested 163 per cent as compared with about a 100 per cent increase if the ground garbage was added to the raw sewage ahead of the grit chamber.

On the other hand, even when allowance is made for the addition of water during grinding, the ground garbage will contain 7 per cent or more, solids as compared with 4 to 5 per cent solids in normal primary sewage sludge. Therefore, the total volume of raw material charged to the digester will be no greater if all garbage were ground and delivered directly to the digester than it would be were the garbage delivered to the raw sewage, and only the settleable portion removed from the primary tanks to the digester. On the basis of the previously given analysis, these volumes would be almost identical; many investigators claim that there is actually a reduction in volume of material charged to the digester when the ground garbage is delivered directly to those tanks.

In any specific instance, complete information on the quantity and character of both the local garbage and sewage should be obtained before deciding upon the digestion capacity required for handling the mixed garbage-sewage sludge, but in general, the addition of all of the garbage of a community will approximately double the digester capacity that would be required for digesting sewage sludge alone. At complete sewage treatment plants, where digester capacity is considerably higher due to the necessity of digesting secondary as well as primary sludge, the addition of garbage would not necessitate such a big percentage increase in digester capacity.

Although the digester capacity required for handling garbage-sewage sludge mixtures will be about the same regardless of whether the ground garbage is added directly to the digester or to the raw sewage, it should be noted that the quantity of gas to be expected from such digestion will be considerably greater if the garbage is added directly to the digestion tanks. Assuming the same degree of digestion in either case, this increase might be 30 per cent.

Lansing, Mich., was one of the first municipalities to adopt the practice of grinding all green garbage and discharging it directly to sludge digesters. Delivery of ground garbage was made by pneumatic ejectors. The plant was completed early in 1938 and included the activated sludge process, as well as primary sewage treatment and garbage grinding. Soon after it went into operation considerable difficulty was encountered with the deposition of grit in digested sludge lines and the clogging of ball valves on digested sludge pumps. This grit resulted from the grinding of bones, egg shells, fruit pits and bottle caps originating in the garbage. The operators found it necessary to flush all digested sludge lines daily and each day removed about 15 to 20 cu. ft. of such garbage grit from those lines. As a result of that experience, most plants handling ground garbage now either discharge that material to the sewage ahead of the grit chambers, or provide special facilities for removing the garbage grit before it is introduced into the digester. However, ground garbage has been successfully handled in the digestion tanks at Goshen, N.Y., without prior removal of garbage grit. There the digestion system is of the two stage type. Ground garbage is delivered directly to the primary digesters by pneumatic ejectors. When sludge is transferred from the primary to the secondary digester it first passes through a manhole before entering a second ejector. Whenever the operator believes it is necessary, he places a wire mesh screen at the point where the primary digester discharge line enters the manhole and in this manner removes the larger inorganic solids. This is done occasionally and is not a regular routine procedure.

Henry Taylor, designer of the plant, believes that the removal of garbage grit is unnecessary if a blow-off head of at least 10 ft. is provided at the primary digester sludge draw-off line and if facilities are provided between the two digesters for removal of the coarser, non-organic material.

Two methods have been used for removing grit from ground garbage before it is introduced into the digestion tanks. The method used at Marion, Ind., provides for the delivery of ground garbage to a pit where water is added to bring the solid content down to approximately 5 per cent. The contents of the pit are then agitated with compressed air which washes the garbage, causes most of the organic matter to float, while still permitting the grit to settle to the bottom. After a few minutes of such agitation all of the contents of the tank, except the deposited grit, is pumped to the digesters.

The other method that has been used is to pass the ground garbage through a grit washer similar to the Jeffrey jig-grit. The overflow from such units, which includes most of the organic matter in the garbage, passes to a wet well from which it is pumped to the digesters. While either of these methods is successful in eliminating grit from the ground garbage, both of them dilute it with additional water so that the material delivered to the digester contains only 4 to 5 per cent solids instead of perhaps 7 to 10 per cent solids that might have been obtainable had grit removal not been considered necessary. Obviously this materially increases the volume of raw sludge delivered to the digester and therefore produces an additional burden on sludge digestion and increased digester overflow liquor. In fact, the solid content of the deliveries to the digester in this case would be no greater than it would be had the ground garbage been delivered directly to the raw sewage ahead of the main grit chambers. Therefore, the only advantage gained by direct additions of garbage to the digester in this manner is the elimination of the previously mentioned effect of ground garbage on chemical precipitation or oxidizing processes of secondary sewage treatment.

Effect of Garbage on Sludge Drying

Rudolfs has investigated the dewatering of fresh and digested sewage and sewage-garbage sludges on vacuum filters. He concluded that fresh sludge from sewage-garbage mixtures can be readily dewatered on vacuum filters with the aid of ferric chloride before or after digestion. The ease of dewatering such sludges after digestion appears to depend on the same factors which determine the rate of dewatering digested sewage solids alone.

In general, all investigators agree that digested sewage-garbage sludge has the same general characteristics as digested sewage sludge, and all experiences indicate that it may be as easily dried on either vacuum filters or sludge drying beds as can be the digested sewage sludge alone. It should be obvious, however, that sewage plants handling ground garbage will require larger drying facilities than would be the case if they received no garbage at all. Even though garbage is high in volatile solids, not all of that volatile matter will be digested and therefore there will be a very material increase in quantity of digested sludge to be dried.

Conclusions

In conclusion, it may be stated that garbage may be ground and added to sewer systems without creating any serious problems, providing such systems, including the collection system as well as the treatment plant, are adequately designed and constructed to receive such material. Where collecting sewers are already subject to solids deposition and putrefaction, or where sewage treatment facilities are already operating at close to maximum capacity, a municipality may be entirely justified in making every effort to exclude garbage from its sewer system.

So far as central grinding stations are concerned, it is obvious that they should only be installed after careful consideration of the condition of the existing sewerage system and the costs of enlarging and operating that system to handle the garbage has been compared with the cost of constructing and operating incinerators or other methods of garbage disposal equally satisfactory from a sanitary viewpoint. So far as domestic garbage grinders are concerned, one may expect it to become increasingly difficult to prevent their installation as the public becomes more familiar with their convenience, and more widespread use results in decreased initial cost of household grinders. Therefore, designers and all others charged with the maintenance or operation of sewer systems, should recognize the probability of gradual increases in sewage treatment loads that are likely to result from the widespread use of these units.

Although existing sewage treatment plants can be altered or enlarged if necessary to facilitate the handling of ground garbage, the same cannot be said for the ability of a receiving stream to handle an additional load of pollution. Thus, it is conceivable that in some cases the admission of ground garbage to the sewage system will necessitate a higher degree of treatment than would be the case if garbage were disposed of by incineration or some other method.

In event the use of central grinding stations is under consideration, the question will naturally come up as to whether such stations may be better placed at the sewage treatment plant or at some more central location providing shorter hauls by the garbage collection vehicles. Time does not permit mention of all of the factors to be considered in arriving at such a decision. I do wish, however, to call attention to one factor which might be overlooked. The practice of using sludge digestion gas for power generation is well known and as the previous discussion pointed out, the addition of garbage to sewage might more than double the amount of gas available for power production, heating and the like. In the writer's opinion, the power to be obtained from such gas might better be used for operating pumps, blowers, or other units that operate practically continuously, than for driving garbage grinders that operate only intermittently. Garbage grinders have extremely large motors. The starting of such large motors would create excessive loads on generating equipment that might otherwise be large enough to supply the power required at the treatment plant.

Use of Lubricating Greases and Oils in Sewage Treatment Plants*

by H. J. MILLER
Chief Operator, Sewage Treatment Plant, Marysville, Calif.

LUBRICATION is one of the most important parts of operation and maintenance costs in sewage treatment plants. How should oil and grease be stored and handled? At the Marysville, Calif., plant there is a separate oil storage room in which oil drums are placed on a horizontal rack. Each drum is equipped with a valve or spigot, under which is placed a drip tray. The drip tray is important, as otherwise there would constantly be oil on the floor due to leakage or careless filling of containers.

Grease is purchased in 10-lb. containers, there being one container in each pumping station and one at the plant. Great care is taken to replace the container cover tightly after each use. If this were not done, dust, insects, and other dirt would enter and later get into the machine bearings.

When taking oil from the storeroom to other locations where oil is needed, 1-gal. glass jugs are used, plainly marked and with tight screw-on lids. The reason for using glass instead of metal is to be able to see any foreign material or moisture that might be in the oil, as well as to reduce waste by overflowing when filling and to be able to see how much remains in the jug.

Each gallon of oil taken from the storeroom is recorded, dated, and initialed by the operator taking it. This record sheet stays in the storeroom and gives a quick check on how much oil is left in each drum, and also how much oil should be budgeted from year to year.

Lubricating Schedules

Should plants have a lubricating schedule? Who should be responsible? The Marysville plant follows a schedule primarily set up by the equipment manufacturers and lubricant manufacturers. This calls for annual, semi-annual, monthly, weekly, and even daily check-ups or changes.

The solenoid or automatic oilers are filled and checked by the night operator. These oilers have glass reservoirs and are easily watched. The night operator also changes the oil in the aeration blower once a week. In this way he is held responsible for these lubricators.

Monthly check-ups are made by the day operators. They consist of removing caps to see if the oil is clean and at the correct level. Most of these reservoirs are not easily checked and should be taken care of during the day. Oil changes are made by the day operators, semi-annually from light oil in the winter to a heavier oil in the summer. Each time an oil change or check-up is made, it is recorded on daily operation sheets.

Can equipment be over-lubricated? The answer to this question, no doubt, has been experienced by many operators—bearing seals going out, bearings heating, gear boxes leaking, and many other incidents. In one case, an operator neglected to turn off an electric drive motor to check the oil level. Thinking the oil to be low, when actually it was being pumped up to a bearing, he filled it to the correct level. This motor had been operating only a few minutes before the oil was put in. After a few hours running the oil expanded — through heat—and burst the oil seal. When this happened, the oil was thrown inside on the motor windings and caused considerable damage.

Do flushing agents need to be used when changing oil in gear boxes or other reservoirs? Although flushing is not now used at the Marysville plant, if metal particles from wear should show up, flushing would be done. Recommended flushes are diesel oil or kerosene; one-half kerosene and one-half S.A.E. No. 20 motor oil is considered the best.

The problem of over-lubrication brings up the question — should a good record be kept of each piece of equipment lubricated? The answer, of course, is yes, because equipment may again be over-lubricated or, to the other extreme, under-lubricated.

When a semi-annual oil change is made, say on April 20, a notation should be made on the corresponding advance daily operation sheet (dated October 20) that the oil change is again due. This saves guess work as to the last date and having to trace back through the sheets to find it.

Safe Use of Lubricants

Can oil be re-used where there is no visible breakdown of the oil bases? Some plants do re-use their oil after it has been filtered or strained, although this has never been the policy at Marysville, where it is thought to be far cheaper to purchase a drum of oil than to have a repair bill. It is very expensive to remove a pump motor and shaft, for instance, and still more expensive to replace or align it. Also, most electric motors in sewage plants are explosion proof, and this fact makes any repair or replacement double in cost as compared to non-explosive motors. Most lubricant manufacturers do not recommend re-using of oils.

Is it possible to change from one brand of lubricants to another? Yes, as most oils and greases have the same specifications. Oils, on the other hand, may vary considerably in their base material. If a change is to be made, it is wise to consult the local distributor. He has all the information on what can be used and what should not be used.

Are oil drippings and grease left on equipment harmful? Very definitely so, as these lubricants tend to soften paint and paint coverings are important in sewage plants. It is also difficult to make paint stay on where oil has been present for any length of time. Where grease and oil are left on equipment, they pick up dust, insects, and other material causing the equipment to look dirty. But the important thing is that this dirt may get into the gear boxes or lubricators when they are being checked or changed.

From a safety standpoint everyone knows what may happen if oil is left on the floor—someone may slip and fall and be seriously injured. This is the biggest repair bill of all and is so very unnecessary. Another point to be remembered is that oil on an uncovered but taped electrical connection may soften the insulating tape; consequently someone could be seriously burned or even electrocuted.

Lubrication in sewage treatment plants is nearly as important as any other part of the operation. Consequently, all handling, storing, usage, and cleanliness of these important maintenance supplies is also very important and should be well supervised.

* Reprinted from *Sewage and Industrial Wastes*, Vol. 26, p. 1048, by permission of FS&IWA.

A Lubrication Check Sheet

By ROBT. C. URBAN
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THE Lubrication Check Sheet shown below will be of help in normal times of operation as well as when adverse conditions prevail.

There are three steps in setting up a lubrication check sheet.

1. Locate every piece of equipment needing grease or oil as a lubricant or as protection.

2. Study the manufacturers maintenance instructions to determine where and when to lubricate and what kind of lubricant to use. Inasmuch as many manufacturers have particular preferences in the matter of lubricants, this may lead to a large number of different types of lubricants and as many grease guns.

It may be much simpler to call in a lubrication engineer from any of the recognized oil companies and have him prepare a lubrication specification sheet for every point of lubrication you have listed.

In this way it may be possible to cut down on the number of oils and greases that will have to be stocked. As few as two oils and two greases may suffice.

3. Prepare the Lubrication Check Sheet following the general idea of the accompanying illustration. List all of the units needing lubrication, the necessary lubrication points, the type of lubricant recommended for each point. Allow space for date of lubrication and initials of operator performing the job.

There is no doubt that the Lubrication Check Sheet will become more and more important to the proper maintenance of operating equipment.

MASTER LUBRICATION CHECK SHEET

1945

GREASE: "HEAVY" - X CO. NO. 2 HEAVY DUTY
"CUP" - X CO NO. 31 CUP GREASE

OIL: "20" - X CO. NO. 341 S.A.E. 20
"90" - X CO. GEAR OIL 90

UNIT	FITTING TYPE	NO.		TYPE OF OIL OR GREASE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SEWAGE PUMP HOUSE																
SEWAGE MOTORS (2) BEARINGS	PIN	2 EA.	G	"HEAVY"												
SEWAGE PUMPS (2) BEARINGS	PIN	2 EA.	G	"HEAVY"												
GREASE SEALS (2)	PRESSURE CUP	1 EA.	G	"CUP"	—		CHECK DAILY & ADD AS REQUIRED									
VACUUM MOTOR BEARINGS	PIN	2	G	"HEAVY"												
VACUUM PUMP	SIGHT FEED	1	O	S.A.E. 10	—		CHECK DAILY & ADD AS REQUIRED									
FLOAT RODS (2)	"SURFACE"	1 EA.	O	"20"	3 TM	1 AK	1 m	1 m								
SCREENINGS GRINDER																
GEAR REDUCER	PLUG	1	O	"20"	CHANGE 3 TM				CHANGE				CHANGE			
(" ")	PLUG	1	O	"20"	CHECK WEEKLY & ADD AS REQUIRED - SEE WEEKLY CHECK SHEET											
LOWER SHAFT BEARING	PUSH	1	G	"HEAVY"	—		TWELVE STROKES DAILY									
MOTOR BEARING	PIN	1	G	"HEAVY"	3 TM											
SLUDGE COLLECTOR																
GEAR REDUCER	PLUG	1	O	"90"	CHANGE 3 TM						CHANGE					
(" ")	PLUG	1	O	"90"	CHECK WEEKLY & ADD AS REQUIRED - SEE WEEKLY CHECK SHEET											
SPROCKET BEARING	PUSH	1	G	"CUP"	GREASE WEEKLY — SEE WEEKLY CHECK SHEET											
MOTOR BEARING	PLUG	1	G	MANUFACTURERS SPECIAL	3 TM											
SLUDGE PUMP																
MOTOR BEARINGS	PUSH	2	G	"HEAVY"												
MAIN BEARINGS	PUSH	4	G	"HEAVY"	3 TM	1 AK	1 m	1 m								
ECCENTRIC BEARING	SIGHT FEED	1	O	"20"	—		CHECK DAILY & ADD AS REQUIRED									
CROSS HEAD BEARING	"SURFACE"	1	O	"20"	—		CHECK DAILY AND KEEP PIN COVERED									
GEAR REDUCER	PLUG	1	O	"90"	CHANGE 3 TM							CHANGE				
(" ")	PLUG	1	O	"90"	CHECK WEEKLY & ADD AS REQUIRED - SEE WEEKLY CHECK SHEET											
CONNECTING ROD	GREASE CUP	1	G	"CUP"	—		GIVE SLIGHT TURN DAILY									
TRICKLING FILTER																
BEARINGS	PIN	5	G	"CUP"	10 TM	6 AK	2 m	2 m								
ROTARY VENTILATORS (3)																
TOP BEARING	"CUP"	1 EA.	G	"CUP"												
BOTTOM BEARING	"CUP"	1 EA.	G	GRAPHITE MEDIUM												
HOT WATER CIRCULATORS (2)																
MOTOR BEARING	OIL CUP	2 EA.	O	"20"	4 AK	2 m	2 m	2 m								
SHAFT BEARING	GREASE CUP	1 EA.	G	MANUFACTURERS SPECIAL	2 AK	1 m	1 m	1 m								
FLOATING COVER																
ROLLER (6) BEARINGS	PIN	2 EA.	G	"CUP"												
VALVES																
6" SCUM WELL PLUG VALVE	PLUG	1	G	PETROLEUM JELLY	—		KEEP VALVES TURNING EASILY									
OTHER 6" PLUG VALVES	PLUG	1 EA.	G	MANUFACTURERS SPECIAL	—		KEEP VALVES TURNING EASILY									
GAS LINE PLUG VALVES	PLUG	1 EA.	G	MANUFACTURERS SPECIAL	—		KEEP VALVES TURNING EASILY									
WORM STEM VALVES	"SURFACE"	1 EA.	G	"CUP"	—		KEEP STEM SURFACE COVERED									
PRESSURE RELIEF F.T. UNITS																
PRESSURE-VACUUM F.T. UNIT	LEATHER DIAPHRAM	1	O	NEATSFOOT		1 m		1 m								
FLAME TRAP UNIT (SPRING)	"SURFACE"	1	G	"CUP"		1 m		1 m								
PRESSURE F.T. UNIT	LEATHER DIAPHRAM	1	O	NEATSFOOT		1 m		1 m								
(" ") (SPRING)	"SURFACE"	1	G	"CUP"		1 m		1 m								
TELL-TALE																
CHAIN	"SURFACE"	1	G	"CUP"		1 m		2 m								
MOTORIZED VALVE																
SLIDE	"SURFACE"	1	G	"CUP"				1 m								
MOVING PARTS	BEARINGS	EA.	O	"90"				1 m								
DAMPER MOTOR																
MOTOR BEARING	"OIL CUP"	1	O	S.A.E. 10		1 m										
CHLORINATOR																
METAL	"SURFACE"	EA.	G	PETROLEUM JELLY	KEEP ALL METAL TUBING, VALVES, PARTS, ETC., COVERED.											

VII—INDUSTRIAL WASTES

THE PROBLEMS of industrial wastes are many, varied, and extreme. According to the U. S. PHS there are more than 10,500 industries which discharge liquid wastes. Of these, approximately one-fourth treat their wastes at least in some degree; another fourth discharge untreated wastes equivalent to a population of perhaps 60 million persons. Data are not available on the remaining 50 per cent but probably half produce organic wastes and the remainder produce inorganic or mixed wastes.

With this tremendous waste load reaching the rivers, lakes and oceans, it is easily understandable that the industrial waste problem represents a large economic loss; a loss in salvageable material, in corrosion, in increased costs of water purification and public health measures, and losses in property values and recreational areas. No one has calculated the extent of the economic loss but it has been estimated to amount to several billion dollars annually.

Quantities of Waste

Some idea of the extent of the waste problem can be obtained from an understanding of the volumes of water used for industrial production. Table 1 indicates water requirements for some typical industries.

Character of Wastes

Industrial wastes are often classified according to type of industry. The general classifications include: Chemicals, Fermentation, Food Processing, Metal Processing, Mining, Petroleum, Pulp and Paper, Textile, and Miscellaneous. In these nine general classifications, there are approximately seventy different industry wastes.

From the considerations of treatment, industrial wastes are often classified as inorganic, organic, and mixed. In general, inorganic wastes require treatment involving chemical and mechanical (physical) processes; organic wastes require treatment by biological processes and possibly also chemical and mechanical processes. Mixed wastes will require treatment involving physical separations, chemical treatment and biological treatment.

Treatment Processes

One of the most effective "waste treatment processes" is by product recovery and although this method of treatment may not show a profit, sale of the byproduct may reduce the cost of over-all treatment. Other operations within the producing plant may also reduce the waste load leaving the plant without unduly increasing the costs of production. These operations include change of processes, separation of cooling water, recycling wastes, and evaporation of highly concentrated wastes. Where these operations will not reduce the waste load sufficiently to make it acceptable to a municipal sewer system or to a receiving body of water, then some form of treatment will be necessary.

The extent of treatment and the processes involved depends on volume and concentration of waste, its toxic content and the dilution available in the receiving water. For each plant, the solution selected should produce the desired result at the lowest possible net cost.

Among the unit treatment processes which may be applied to wastes are those listed immediately below, but not every one of these processes is applicable to every type of waste:

Aerobic biological oxidation
Anaerobic digestion
Chemical Coagulation
Chemical Oxidation
Chlorination
Deionization
Dewatering
Drying
Filtration
Flocculation
Flotation
Incineration
Ion Exchange
Lagooning
Neutralization
Screening
Sedimentation
Spray Irrigation
Vacuum Filtration

Industrial Waste Surveys

Where industrial wastes are discharged directly to streams and abatement of pollution is desirable, a survey of the problem is the first step. Governmental bureaus are usually interested in such surveys and may participate. Within a community the survey may be performed by municipal engineering services or consulting engineers. In any industrial waste survey, no matter by whom conducted, the purpose is not to persecute industry but to establish the extent of the problem and the solution.

The first step in an industrial waste survey is to obtain adequate publicity to the general public and the industries emphasizing that the cooperation and aid of industry is the paramount consideration. The second step is to list and classify all industries within the area surveyed. From this classification, industries having no liquid wastes (except sanitary) may be eliminated. Other classes should be listed in order of known relative strength or importance. The third step is to request each industry by letter to appear at a conference with representatives of the organization making the survey. The fourth step is to conduct an actual investigation of the sewers and wastes within a plant, the plant processes, etc. This part of the survey involves not only questions of plant management but also measurement, sampling and analyses of the actual wastes. From this information the solution to the problem usually can be devised.

TABLE I
Industrial Water Requirements

Type of Industry	Unit of Production	Gal of Water Used per Unit
Chemical Industries		
Starch	ton	333
Alcohol	ton of grain	20,000
Amm. Sulfate	ton	200,000
Food Processing		
Beet Sugar	ton	25,000
Canning	100 cases	200 to 25,000
Meat	live units	16,000 to 55,000
Milk Products	100 lb	200 to 250
Textiles		
Cotton	100 lb	1,000 to 3,000
Linen	100 lb	10,000
Rayon	100 lb	8,000 to 10,000
Wool Scouring	100 lb	2,000 to 12,000
Petroleum		
Oil Refinery	100 bbl crude	77,000

Buying and Using Lime

Its neutralizing value depends upon reactivity and basicity

By RICHARD D. HOAK
Senior Fellow, Mellon Institute, Pittsburgh, Pa.

IT is probable that *for neutralizing acidity* lime is used more extensively than all other substances. Over a long period of time, lime has found many applications as a neutralizing agent, because of its relative cheapness and general availability. But in spite of long experience with it, a number of misconceptions still persist about the chemical properties of lime and the technology of using it efficiently.

Among some users, the word "lime" signifies a fairly definite article of commerce. This leads to the belief that all limes are much the same, regardless of their source. Lime manufacturers are fully aware that this is not so. Each endeavors to make products of consistently uniform quality, to guarantee that month-to-month variations in the chemical and physical properties of their particular merchandise will be small. But the great variation in composition and structure of limestones from different quarries, and the variations of calcination practice, yield limes whose properties differ widely.

Several Types of Lime

All limestone quarried for conversion to lime contains small to moderate amounts of impurities, of which silica, iron oxide, and alumina are the most common.

Fig. 1 illustrates spectographically the variety of impurities that may occur in commercial limes. Samples 1 and 2 are commercial high-calcium and dolomite limes, 3 and 4 are U.S.P. lime and magnesia, respectively. Note that the boron in the U.S.P. magnesia sample shows that it was recovered from sea water.

In addition to impurities, limestone may contain magnesium carbonate in amounts from almost zero to equimolar proportion with its calcium carbonate. Stone containing less than 10 per cent magnesium carbonate is considered to be high-calcium limestone; if more than 10 percent is present, it is called magnesian limestone.

Dolomite is a definite mineral consisting of a crystalline matrix of the double carbonate of calcium and magnesium. In some limestones the two carbonates are intimately intermingled in approximately equimolar proportions, but not crystallized as a double salt; such stones also are usually called dolomite. Where magnesium carbonate is present in substantially greater proportion than calcium carbonate, the stone is termed dolomitic magnesite. With such a variety of raw materials it is obvious that limes can be made with properties that vary over a considerable range.

Neutralization Economy: Three Important Factors

Deliverd price, available basicity, and reactivity are factors of fundamental importance for economy in neutralization. The low cost of lime may suggest that savings resulting from careful attention to efficiency in neutralization practice would be insignificant. There are many plants at which upwards of $100,000 is spent annually for lime to neutralize acidic waste waters. Thoughtful analysis of the neutralization problem, both in plant design and operation, can readily yield appreciable savings, even where modest operating costs are involved.

Price

Where industrial wastes are to be neutralized, it is axiomatic that the cheapest agent capable of fulfilling the requirements should be used. But delivered cost per ton is not usually a sound criterion of the actual cost of available basicity. Limes selling for the same price can have quite different chemical properties. Buying a product at a premium price often results in net gain through economy in operation. Where purchases are made direct from the manufacturer, a user can generally be sure of getting a product of dependable uniformity. Purchase from a jobber can be risky, however, unless a definite brand is specified. In any case, wherever possible, even cheap neutralizing agents should be held to specifications by routine analysis.

Available Basicity

Where lime is bought to neutralize acidity, the purchaser is really paying for available basicity. The same price is paid for the inert material in lime as for the reactive fraction. Actually, the inert material costs more, since it increases the final sludge volume without contributing to the reaction, and thus adds to the expense of sludge removal. The cost per unit of basicity must be used, therefore, if the prices of different neutralizing agents are to be compared fairly.

Chemical analysis of lime is time-consuming, and it cannot be depended upon to provide an accurate measure of available basicity. This results from the fact that some of the calcium and magnesium oxides may combine with silica, iron oxide and alumina during calcination to form compositions that are insoluble in acids. Routine chemical analysis determines total calcium and magnesium without revealing how they are combined with other elements. Where the original stone contains an appreciable proportion of inerts, the potential basicity of the lime may be reduced considerably, especially if overburning has been severe. Also, the reactivity of lime decreases with the degree of overburn, and neutralizing power is thereby lost.

The only sound way to determine available basicity is to measure it under conditions simulating those of actual use. Such a determination can be made easily and quickly in the laboratory. A moderate excess of a representative sample of the acidic liquor, at the temperature to be expected in practice, is mixed with a known amount of neutralizing agent for a definite time. The excess acid is titrated, and available basicity calculated, as grams of equivalent calcium oxide (CaO) per gram of sample, for the time and temperature of the determination. If the agent is quicklime, it must first be slaked; if hydrated lime, it must be suspended in water. A series of determinations should be made at a number of uniformly longer time intervals. In some instances it may be desirable to run several series at different temperatures, to decide upon the best operating conditions.

This procedure can be quite useful for attaining maximum neutralization efficiency. By adopting a set of standard conditions (acid volume

and concentration, weight of sample, temperature, and mixing time) it provides a rapid method for checking the quality of each shipment of neutralizing agent; but care must be used in preparing a sample that is truly representative of the shipment. It can be used to determine whether the proper amount of agent is being applied in existing plants; and, if so, whether the correct mixing time is being provided for maximum utilization of basicity. It is especially useful in designing a new plant because it provides a rational method for estimating capacities. Finally, it permits holding to a minimum the excess of agent that is customarily added as a safety factor.

Reactivity

The composition and structure of limestones, plus calcination practice, conspire to yield limes with a wide range of reactivity. Highly reactive limes are usually essential for optimum neutralization efficiency. Reactivity rarely has any influence on the price of lime, but it has a direct bearing on the capital and operating costs of a neutralization plant. The more reactive the lime the smaller the plant need be to treat a given volume of acidic liquor — and the lower the operating cost. Under our present tax laws, the capital cost of a treatment plant is very important because it must be added to the plant investment of the producing company; it cannot be charged against profits as an operating expense.

Reactivity cannot be measured by ordinary chemical or physical analysis. It can be estimated roughly by observing the settling rate of a lime suspension. Normally, lime suspensions that settle slowest are the most reactive. Reactivity can, however, be determined accurately by the procedure for available basicity. A series of determinations, in which three of the variables are held constant while the fourth is varied, will give precise information on reactivity. Mixing time is the variable that would ordinarily be studied, because the other three are often fixed by local conditions. Actual operating practice should always be simulated as closely as possible.

Influence of Calcination Practice on Reactivity

Lime and magnesia must dissolve before they can react with an acid. Both react with water and go into solution as hydroxides. Calcium hydroxide is slightly soluble (1.7 g/l) and magnesium hydroxide is rather insoluble (0.01 g/l). These substances are therefore used as aqueous suspensions in neutralization processes. The rate at which they can react with an acidic liquor is governed directly by their rates of solution. This rate is controlled primarily by the concentration of the substance in the surrounding water, and the exposed surface of the solid material.

Particle Size and Solubility Rate

Where the hydroxides are reacting as rapidly as they dissolve, there is a driving force which promotes solution from the solid phase. But the rate at which solution can occur is proportional to the area of the solid. Thus, the smaller the particles, the more rapidly they will dissolve. This is why the most reactive limes are those that yield the finest particles when they are hydrated. Certain dissolved substances increase the solubility of lime and magnesia in water, and some decrease it. This must always be remembered when the reactivity of a lime is compared in different solutions.

Among the several factors responsible for the reactivity of a lime, calcination practice is the most important. This is so because calcination technology can be designed, within limits, to fit the requirements of a particular stone or product. When limestone is calcined, its carbonate decomposes and the carbon dioxide escapes. In this process the stone does not disintegrate, but retains its original crystalline structure. The resultant lime should therefore have a very porous and fine-grained structure.

Porosity Is Determined by Lime Density

The true density of lime varies but little, whereas its apparent density can be widely variable. Porosity, which is a significant factor in reactivity, is the ratio of apparent density to true density. Apparent density, in turn, is governed partly by the manner in which the stone has been calcined. A fairly pure high-calcium stone, if properly calcined, can yield a lime having more than 50 per cent pore space.

Although the melting point of pure calcium oxide is very high (about 4650°F), it begins to soften at a comparatively low temperature. For this reason, the initial fine-grained structure of lime may change rapidly on continued exposure to heat. As a result, the surface area of the lime may be reduced considerably. It should be noted that brief exposure to a very high temperature may have the same result as long exposure to a relatively moderate temperature.

The impurities in lime tend to increase reduction in surface area by lowering the temperature at which softening occurs. In addition, these impurities combine with calcium and magnesium oxides at high temperature to form compounds or solid solutions which cause a portion of the lime to become wholly or partly inactive. Since the reactivity of lime is a function of both surface area and calcium oxide content, it is clear that calcination technology can exert a profound effect on this property.

Magnesian and Dolomitic Limestones

Most of the statements made about high-calcium limes apply equally to those containing substantial amounts of magnesia. Where limes contain more than about 10 per cent of magnesia, however, certain additional factors must be recognized.

When magnesian limestones are calcined, the burning must be carefully controlled to produce the desired type of product. Calcium carbonate dissociates at about 1650°F, and magnesium carbonate at about 1380°F, at atmospheric pressure. This means that complete dissociation of the calcium carbonate fraction of a stone will result in some overburning of the magnesia that was formed first. In practice, the temperature differential between the two carbonates is probably lower than 270°F, because of the effect of factors that are not well understood.

Nevertheless, calcination of magnesian stone requires precise control of kiln operation to insure minimum overburn of the magnesia. Like lime, the reactivity of magnesia decreases with the degree of overburn. Since the low solubility of magnesia makes it normally less reactive than lime, overburning can easily change it to an inert component of the finished product.

Advantages and Disadvantages

Magnesian and dolomitic limes have two principal advantages over high-calcium lime. The lower combining weight of magnesium oxide permits it to neutralize about 1.4 times as much acid-equivalent as calcium oxide, and magnesium sulfate is about 150 times as soluble as calcium sulfate. Both of these properties are economically important. High-calcium and magnesian limes usually sell for the same f.o.b. price.

Freight rates being equal, a purchaser therefore pays less per unit of basicity, in proportion to its magnesia content, when he buys magnesian lime. The relatively high solubility of magnesium sulfate can keep sludge volume to a minimum, and thereby reduce the cost of sludge disposal.

These desirable properties are counterbalanced by several disadvantages. Obviously, nothing will be gained, and a great deal may be lost, by using overburned magnesian lime. But even reactive magnesian limes have peculiar properties that detract from their usefulness. The magnesia fraction of a lime is most reactive in strongly acid solutions; its reactivity decreases as the pH of the solution rises, and, at high pH values, it does not react at all. This property indicates that dolomitic lime can be used most advantageously in applications where complete neutralization is not required, because its reactivity declines rapidly at pH values above 6.

By incorporating special features in the design of a neutralization plant, however, dolomitic lime can be used effectively at pH 9 or somewhat higher. Fig. 2 illustrates laboratory equipment used to determine the rate of reaction of dolomitic lime.

Practical Applications

Two examples may serve to illustrate the peculiarities of neutralization with dolomitic lime. The spent liquor from pickling steel with sulfuric acid is commonly neutralized with lime, and this process has been studied in detail, both in the laboratory and in the field. Properly slaked high-calcium lime rapidly neutralizes the acid and precipitates the iron in pickle liquor. This is a simple operation, requiring only that the proper amount of milk of lime be thoroughly mixed with the spent liquor.

When a milk of dolomitic lime is used under the same conditions, completion of the reaction takes five hours or more, instead of 15 to 20 minutes. This results directly from the relatively low reactivity of the magnesian fraction of the lime.

When the two reactants are mixed, the lime fraction reacts promptly with the free acid and ferrous sulfate. This raises the pH of the solution, thereby decreasing the reactivity of the magnesia. As the neutralization approaches completion, therefore, the reaction becomes progressively slower because of a diminishing driving force for solution of magnesium hydroxide.

Finally, the neutralization is completed by the least reactive portion of the magnesia fraction. But this takes a long time, and the size of the neutralization plant must be large in proportion. If the rate of the neutralization reaction could be increased, advantage could be taken of the lower cost of basicity of dolomitic lime.

Factors Affecting the Reaction Rate

When ferrous hydrate oxidizes, it releases hydrogen ions; this lowers the pH of the solution and increases the reaction rate. Oxidation of ferrous iron can be promoted by exposing it to air. This can be done easily by direct aeration or by using an agitator that inducts air, such as a Turbo-Mixer. Increasing the temperature also increases the reaction rate, as does the addition of a small excess of lime.

It has been found that by provision of adequate aeration, by operation at 170°F or higher, and by using a five per cent excess of lime, pickle liquor can be neutralized in less than an hour with reactive dolomitic limes that otherwise would require five hours. Adoption of these measures should permit neutralization of pickle liquor at a cost no greater, and possibly less, than for high-calcium lime.

In another instance, a large enough excess of dolomitic lime was added to an acidic waste to raise the pH to 6.5 in about two minutes. In this case only the lime fraction reacted, and all of the magnesium oxide component was found in the sludge. When the reaction time was increased, the amount of lime added could be reduced and still develop a pH of 6.5; at the same time, the magnesia reacted completely. This experience illustrates the fact that where reaction rates are increased by adding a large excess of dolomitic lime, the magnesia component is not only wasted, but it needlessly increases the sludge volume.

Where dolomitic lime is used to develop a high pH, it is important to recognize that magnesium hydroxide is insoluble at pH 10.5 and above. If it is desired to raise the pH of a solution above 10.5 with dolomitic lime, the lime fraction will first have to precipitate all the magnesium salts in solution. At pH 10.5 all magnesium will have been precipitated as the hydroxide; above this point only the lime fraction will be effective in raising the pH further.

Improper Slaking Causes Diminished Reactivity

The effect of slaking on reactivity is not always fully appreciated. Both lime and magnesia must be converted to hydroxides before they can go into solution and react with acidic substances. The rate of hydration depends partly upon the composition of lime and the way it has been made, and partly upon slaking technique. Where lime is intended for chemical uses, improper slaking can reduce its reactivity seriously.

In general, the more rapidly a lime can be hydrated completely, the finer will be the resultant particles. This can best be accomplished by slaking with that volume of water, preferably warm, which will develop the highest practical slaking temperature. Too much water results in drowning the lime, too little in burning it; both amounts reduce its potential reactivity.

The rate of hydration of different limes varies so much that the proper amount of water to use must be determined by trial; usually, about four pounds of water per pound of dry lime will yield a reactive slurry.

Magnesium oxide hydrates much more slowly than calcium oxide. Where magnesian or dolomitic limes are used for neutralization, it is desirable to allow the heavy suspension to age for several days before dilution to a milk suitable for use in neutralization equipment.

Dry-hydrated limes often are used for neutralization at small installations. In such instances, the higher cost of basicity is overweighed by convenience in handling. A freshly slaked lime, however, will be more reactive than the same lime that has been dry-hydrated.

Sludge Volume

Disposal of the sludge resulting from lime neutralization can be quite costly. Where land is available, the sludge may be lagooned. But lagoons are unsightly, and they always seem to fill up faster than anticipated. If sludge must be hauled to a dump, the expense can be burdensome.

Sludge frequently is unavoidable as a by-product of lime neutralization. Measures that can be taken to hold sludge to a practical minimum will nearly always be economically sound. Some limes produce a larger sludge volume than others. The lime that produces the least sludge, without an undue sacrifice of reactivity, should always be used. In conventional plants neutralizing sulfate liquors, dolomitic limes generally

produce a larger sludge volume than high-calcium limes of equivalent quality. This often has been a source of misunderstanding. Although magnesium sulfate is quite soluble, dolomitic limes tend to make a fluffy, bulky sludge with a lower dry solids content than their high-calcium counterparts.

Neutralization Techniques

Lime neutralization seems to be a very simple operation. It appears that the desired result can be attained easily, just by mixing the proper amount of lime slurry with the acidic liquor. Many operators believe that nothing else is worth bothering about, and some of these do not even provide satisfactory agitation. Where the several factors important to lime neutralization have been taken into account, potential gains can readily be cancelled by poor mixing. Apparently it is not obvious that thorough agitation is essential for complete utilization of basicity. Efficient mixing is particularly important where salts of heavy metals are present in the acidic liquor.

Fortunately, a technique has been developed which permits full use of the basicity of any lime, and, at the same time, produces a minimum sludge volume. Developed primarily to reduce the cost of pickle liquor neutralization, the procedure can be adapted to many other problems.

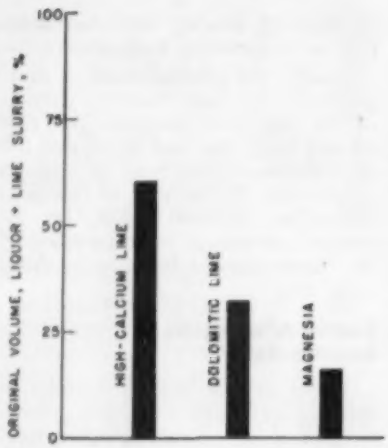
Simple Process in Commercial Use

Operation of the process comprises feeding streams of pickle liquor and milk of lime in stoichiometric proportion to an agitator-aerator held at 170°F or above, and continuously filtering the resultant slurry. The aeration is controlled to maintain a ferric/ferrous ratio of 2.5 to 3.5 in the mixture; this yields a precipitate that settles and filters very rapidly.

Aeration should be provided by a mechanical device for dispersing air, such as a Turbo-Mixer; porous diffusers or bubbling devices do not disperse the air adequately for rapid oxidation.

If the liquor is treated hot, as it comes from the picklers, no supplemental heat is required, but it is important that the temperature of the mixture be at least 170°F.

The process forms a slurry with high-calcium lime that can be dewatered on a vacuum filter at a rate of 400 pounds of cake per square foot per hour, and the cake will contain 60 per cent dry solids. The slurry from dolomitic lime does not filter quite as rapidly, but the process permits full utilization of the basicity-advantage of this material.



SLUDGE from neutralized pickle liquor
The minimum volume resulting from three types of lime, using procedure described by the author.

The process is simple to operate, and it has been in commercial use for several years. The final sludge volumes for pickle liquor neutralized by this process are shown graphically in Fig. 3.

A Dry-Lime Process Is Convenient but Costly

Where the volume of acidic liquor does not exceed a few thousand gallons per day, the dry-lime process developed by C. J. Lewis can sometimes be used to advantage. The liquor is treated with a considerable excess of dry hydrated lime and allowed to settle. The excess lime creates a granular sludge that dewaters readily on a rotary vacuum filter.

At a commercial installation, the filter cake is discharged directly to a truck, which hauls it to a dump. Convenience of operation justifies the substantial excess of lime required by the process; it would be too costly for large installations.

Research Pays Dividends

In these days of widespread industrial research it is unnecessary to stress the fact that such activities have been immensely profitable. It would be incorrect to assume that the monetary gain of the sponsors of research is the sole benefit it confers. Research is responsible more than anything else, for the steady improvement in our standard of living. Basically, research is a persistent seeking for facts that will increase our understanding of the environment in which we find ourselves. In its synthetic aspect, research combines seemingly unrelated facts and thus evolves new ideas, new products, and new industries. Research is autocatalytic, because it is catalyzed by its own products.

Lime is very likely the oldest chemical made by mankind. It has been made and used for such a long time that it is almost taken for granted. The fact that it is venerable may cause some of us to think we know all about it, and that research would be a waste of time and money. That this is far from the truth is illustrated by the advances that have been made in neutralization technology in recent years.

Always More Needs for Neutralization

Basic data on the economics and technology of neutralization with limes and limestones were developed by the Fellowship of the American Iron and Steel Institute at Mellon Institute. This work was undertaken to supply the steel industry with dependable data not otherwise available. Some individual lime companies apparently were stimulated by this research to embark on pilot studies which resulted in highly useful information. But much investigational work still remains to be done.

The increasingly rapid progress that is being made in the field of stream pollution abatement affords good evidence that more and more acidic wastes will require neutralization. This is an expensive operation. It is costly not only by reason of the neutralizing agent that must be purchased, but because sludge disposal is a vexatious problem. Nevertheless, the opinion has often been expressed that it is preferable to neutralize, instead of attempting to operate a complex recovery process that may only break even. Here is a real opportunity to provide industry with fundamental research data that will help solve a problem that is steadily becoming more troublesome.

Note:

The techniques mentioned in this paper are described in detail in "Disposal of Spent Sulfate Pickling Solutions," published by the Ohio River Valley Water Sanitation Commission, Cincinnati 2, Ohio.

VIII—DESIGN AND CONSTRUCTION

MANAGEMENT, operation and maintenance of water and sewage works occupy most of the attention of persons engaged in the supervision and operation of water utilities or sewage facilities. Two other responsibilities often are assigned to such personnel are: Design and Construction supervision.

In many cases, consulting engineers are called in to do the design work and supervise construction but the water or sewage manager, superintendent or engineer frequently handles smaller jobs himself or at least must be familiar with the problems involved and the extent and progress of the work. The subject of design factors is best understood if he is familiar with the subject of water supply and sewage treatment. Construction, on the other hand, requires a knowledge of equipment, machines and techniques not used in plant operation.

Trenching

It does not matter whether it is a water utility or sewage works, the laying of water mains or sewer lines involves the same problems and equipment.

One of the common jobs in laying lines is that of breaking the pavement. Power-operated hand tools are necessary to this work. These may include hand held tools operated by compressed air, electricity, or self contained gasoline engines. These tools may be fitted for a wide variety of jobs from a chisel blade for cutting asphalt to a moil point for breaking concrete or foundation, or a narrow gad for removing brick or stone blocks.

Portable air compressors of 60 to 500 cfm capacity may be used for operating air driven tools. The number of water and sewage works which have their own air compressors continues to grow as the need for and versatility of these machines becomes apparent to superintendents of water and sewage works.

Next job after breaking pavement is that of excavating trenches. Trenching machines will save both time and money over pick and shovel excavation. There are many types of trenching machines available and their use depends on width and depth of trench, type of soil, presence of other underground facilities and other factors. The most common types of excavation equipment used includes trenchers, back hoes, clam shells, drag scrapers and power shovels.

Trenchers or ditchers may be of two kinds; one carries ten or more digging brickets on a large wheel, the other on a boom. The latter is sometimes termed a ladder-type digger. Trenchers are used for ditches up to 4 ft wide, clam shells and power shovels will cut any size trench, the former are used for deep trenches.

In digging trenches, provision must be made to prevent caveins in the trench walls. This usually is done with sheet piling properly braced. Backfilling must be done after the water pipe or sewer line is installed. For this purpose either a bulldozer to push the dirt into the trench, or a drag scraper may be used. When the trench is backfilled, the soil must be settled either by puddling or by tamping. Pneumatic tampers can be operated by hand, or mechanical rammers, gasoline driven, may be used.

Tunnelling is a necessity in many locations. House connections can often be laid in this way, using either boring or pushing machines. Holes of 2 in., 8 in. or up to 36 in. in diameter can be bored by special equipment. Pipe up to 4 in. in diameter can be pushed without tunnelling in good soil for distances of 50 to 150 ft There are several makes of pipe pushers on the market using hydraulic power, hand or gasoline motor.

For large tunnels the Armco Co. furnishes liner plates for tunnels ranging from 4 to 33 ft in diameter. The construction of large tunnels is usually not in the domain of the operating manager but laying water mains and sewers of nominal size is a problem he may face often.

Dewatering

When ground water interferes in the laying of water mains or sewers, it is necessary to remove it by pumping. Trench water is removed by diaphragm or centrifugal pumps, operated by gasoline or electric motor. Hand operated diaphragm pumps are also used where the quantity of water is not great. Centrifugal pumps must be self-priming and non-clogging. There are many dewatering pumps on the market.

Another method of reducing water in trenches or other excavations is the well point system. Well points are driven to a depth of 5 ft or more below the trench depth and the points are usually 2 in. in diameter and are spaced from 3 to 6 ft apart, some 2 to 5 ft outside the trench along one side. These well points are connected to a single header connected to the suction of a pump. The depth, spacing, number of well points, etc. depends on the depth of trench, length of trench open and amount of water. Excavations for building structures can be dewatered by the same system.

Installing Mains & Sewers

The techniques of installing water mains is a matter requiring considerable skill, from the preparation of the bed to the lowering of the swabbed pipe and the jointing either with lead or sulfur joint compounds. The techniques of installing sewer pipe, particularly tile, does not require quite so much care in installation. On the other hand, more care and attention given to laying and jointing pipe the better the sewer, the less likely that it will leak or allow infiltration and the less the possibility of the entrance of tree roots.

Concrete Construction

Concrete is generally used for building foundations, manholes and sewers. Modern construction practices generally use concrete mixed at a central plant or truck mixer. Forms for manholes, tanks, sewers, etc. can be obtained from several manufacturers.

Prefab Construction

In place of concrete structures, prefabricated steel underground structures are used particularly for underground pumping stations on sewer systems. Many advantages are claimed for this type of construction.

Materials of Construction

Water lines require pipe; sometimes cast iron, sometimes asbestos cement, sometimes steel. In addition, all pipe lines use valves (cone, butterfly, gate, or plug) and fire hydrants. Sewer lines use sluice gates.

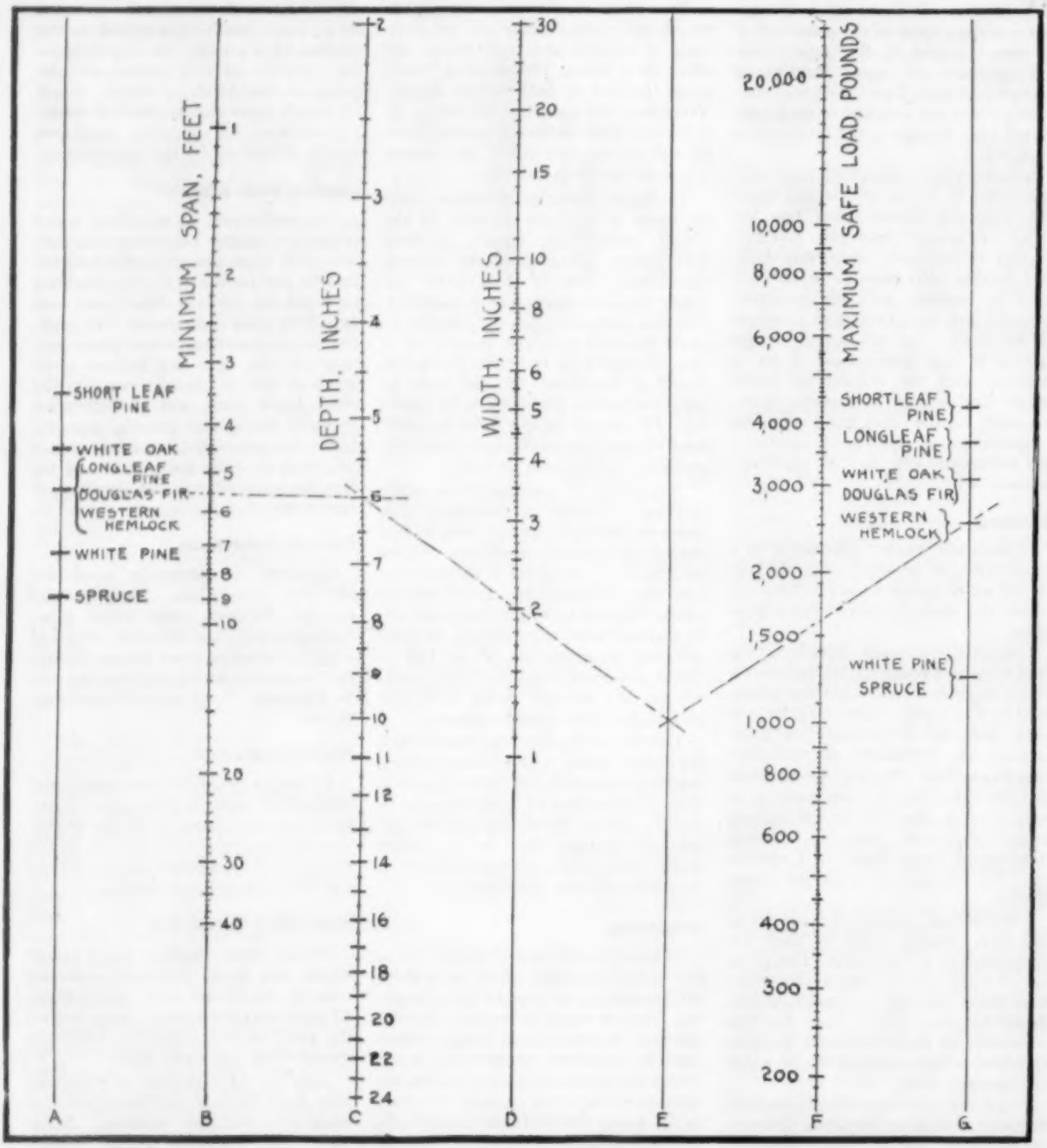
Any list of materials of construction must include corrosion resistant materials, such as ceramics, alloys, etc.; other materials include protective coatings, points, lacquers, plastics, rubber base paints, etc.

In the building of water and sewage facilities there are few materials of construction or equipment necessary to contracting that are not used. The construction of water and sewage works makes up a significant part of the total construction value each year.

Safe Loadings For Wooden Beams

By W. F. SCHAPHORST, M.E.

Newark, N. J.



THE above chart will be found handy for many purposes—in the selection of safe beams made of ordinary woods such as shortleaf white pine, white oak, longleaf pine, Douglas fir, western hemlock, white pine, and spruce. The chart is based on data adopted by the American Railway Engineering Association for safe, uniformly loaded wooden beams of rectangular section.

Example: It is desired to hold 200 lb. per foot on a wooden beam of 2 in. by 6 in. western hemlock over a span of 5 ft. Will the beam be safe?

Run a straight line from the point in column A opposite "western hemlock" over to the depth 6 in column C. The intersection with column B shows the minimum span to be 5.5 ft. The beam will therefore be safe as regards span.

Then from the depth 6 in column C run a straight line through

tne width 2 in column D and locate the intersection in column F. Then from that point of intersection run a straight line over to the point in column G opposite "western hemlock." The answer is found at the intersection with column F and is 1,600 pounds.

Since it is desired to hold only 5 × 200 or 1000 lb. on the 5 ft. beam, and since the beam will actually hold 1,600 lb., it certainly is amply safe. In fact, the chart shows that a beam made of white pine or spruce would be safe under this load.

Inversely, the chart may be used for finding any unknown factor or factors. If the kind of wood and the span are known, the first straight line through columns A, B and C gives the minimum depth of beam which must be used. If the width of beam is unknown, the line through the columns E, F, G is located next, and lastly the line through columns C, D, E gives the minimum width of beam in column D.

The weight of the beam itself is included in the safe load given in column F, hence the user of the chart need not worry about that factor.

Safe Loadings For I-Beams

By W. F. SCHAPHORST, M.E.

THE accompanying chart reveals how much any ordinary I-Beam will hold under the very *worst* condition, with the load concentrated in the middle of the span as shown by the sketch on the chart. The chart, for the sake of safety, is based on concentrated loading.

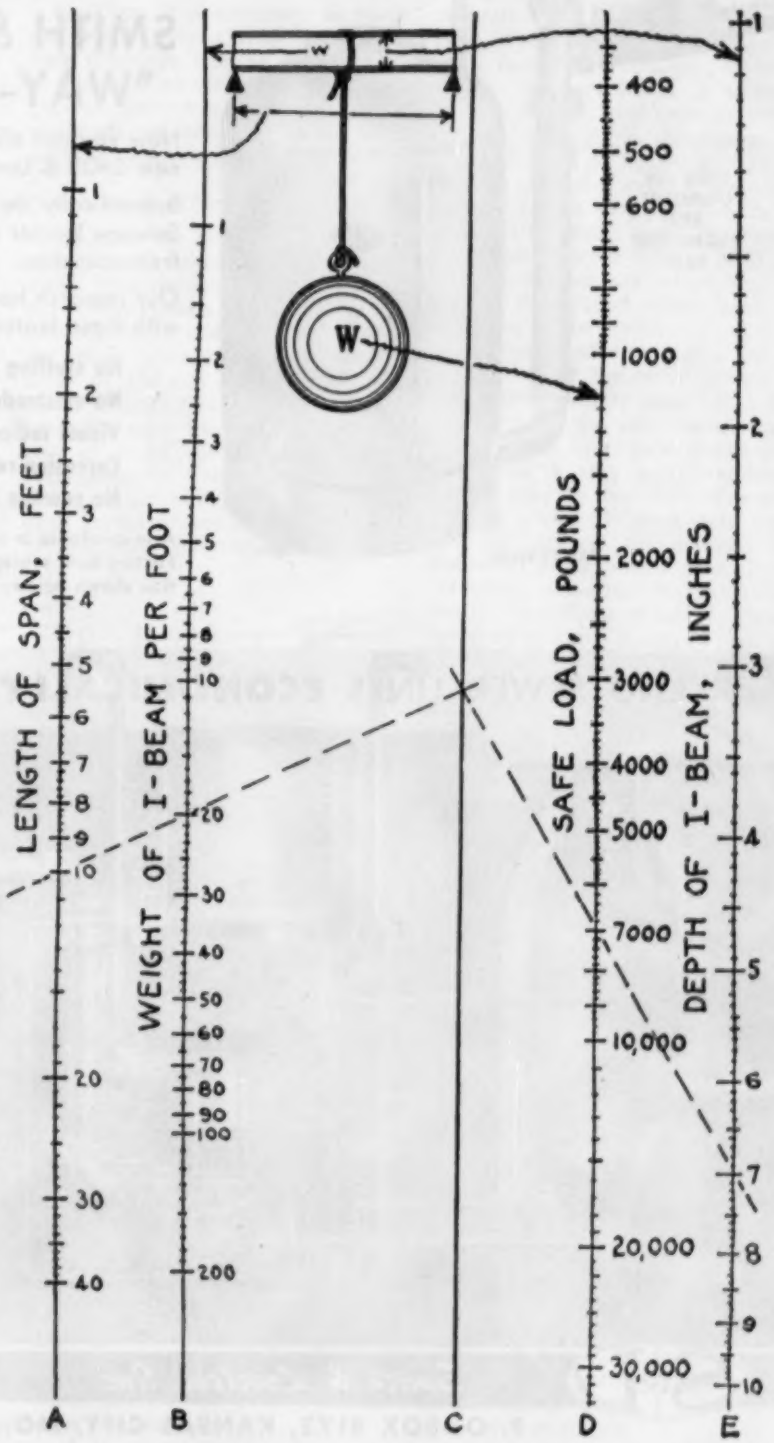
Let us suppose that a weight of 4,000 lbs. must be supported. A 7-inch I-Beam, weighing 240 lbs., is available. It is 12 feet long, and therefore weighs 20 lbs. per foot. The minimum distance between supports that can be obtained for the lifting operation is 10 feet. Is the I-Beam strong enough to lift the 4,000-lb. load?

The Answer

Run a straight line through the 10-ft. (column A) and the 20-lb. (column B) and locate the intersection in column C. Then, from that intersection in column C, run over to the 7-in. (column E). The intersection through column D shows that the I-Beam will support 7,000 lbs. Since the load to be lifted is only 4,000 lbs. the beam is amply strong. In fact, the reader can easily find, by applying the chart, that a 4-inch I-Beam, all other conditions being the same, would safely support the load of 4,000 lbs.

Similarly, it is easy to ascertain the maximum allowable span when the factors in columns B, D and E are known. Or, the necessary weight per foot of I-Beam may be determined when the factors in columns A, D and E are known. Lastly, the depth of beam is determinable when the factors in column A, B and D are known.

For loads that are "uniformly distributed"—not concentrated—the safe loads in column D may be multiplied by two. Thus, the above described beam will support a uniformly distributed load of 14,000 lbs., or 1,400 lbs. per running foot.



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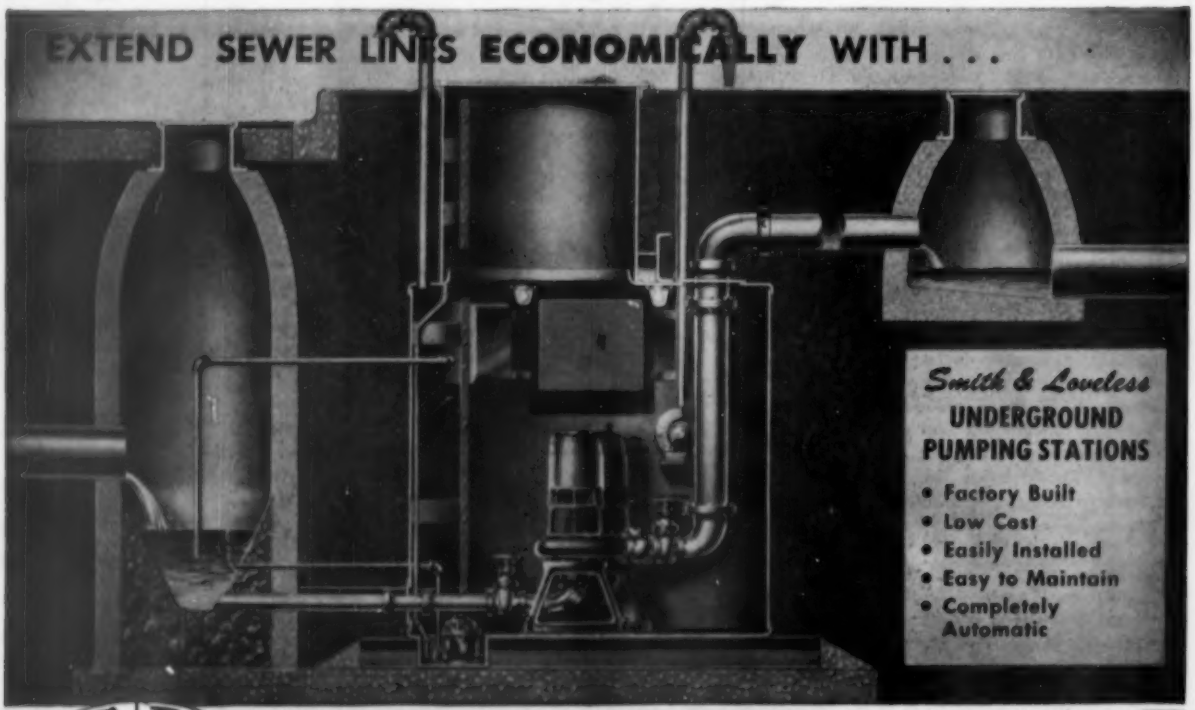

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Notes on Design of Sewage Pump Stations

By ALDEN SMITH
Smith & Loveless, Kansas City, Mo.

THIS INFORMATION has been compiled from reference books as well as from observation of some better designed pump stations. Much of the material will seem elementary but it is offered with the thought it will be convenient as a ready reference.

Need For Pumping

1. Where the topography is such that good sewer grades are not possible with gravity flow, without excessive depth and with consequent high construction costs. The sewer grade is carried as low as is practical, then the sewage is raised by a pump station to bring the sewer close to surface again.

2. Where the sewer discharges into a river or other body of water with the hydraulic grade of the sewer below the river surface. In many cases such pump stations are only used during high water or flood conditions, and are by-passed most of the time.

3. Where the hydraulic grade is such that there is insufficient head for gravity flow through a treatment plant.

4. Where it is necessary to boost the sewage over a ridge through a long discharge line, or force main, to a point from which it will flow by gravity. Such force mains are generally of cast iron pipe of the kind used for water mains.

Determination of Pumping Rate

Most of the volume of sanitary sewage and industrial wastes originates from the water supply. Hence, any determination of needed pump capacity should start with the records for water consumption for similar areas of the city. Actual measurements indicate that sewage flow will normally vary from 70 to 130 per cent of water consumption. Therefore, designers often assume that the average (not peak) rate of sewage flow, including some allowance for ground water infiltration, will equal the average rate of water consumption.

The amount of ground water which infiltrates into the sewers through poor joints, cracked pipe, manhole walls, basement drains, etc., varies so widely that prediction is difficult. When available, local experience data are the best guide. Maximum infiltration rates of 50,000 gallons per day per mile of sewer are frequently encountered in well built sewers below ground water level. A common design allowance is 1000 to 2000 gallons per day per acre served, depending on the ground water level and condition of the sewer.

The maximum rate during the day is used to set the pump design capacity. For sanitary sewers in a residential area, the maximum is generally two to three times the average flow. For a very small residential area, it may be four times. For commercial areas, the peak may reach 150 per cent of the average. For industrial areas it will generally be somewhat less. Most text books and health department standards recommend an assumed design flow of 250 gallons per day per capita for normal residential areas which have a water consumption of 60 to 125 gallons per capita per day. When sewers are below the ground water level an allowance for infiltration should be added to this peak figure at the rate of 1000 to 2000 gallons per acre per day.

For storm water flow the rate is best estimated by the formula

$$Q = \frac{CiA}{43{,}200}$$

where Q = Flow in cubic feet per second
A = Drainage area in square feet
i = Average intensity of precipitation in in. per hr
C = Coefficient of run-off

The coefficient of run-off will vary with the duration of rainfall at the assumed rate, the condition of saturation from previous rains, the kind of surface, and the time required for flow to reach the drain from the farthest point.

Commonly, C will vary from 0.6 to 0.95 for impervious surfaces, or from 0.2 to 0.60 for pervious surfaces. (Note: Because 1 acre = 43,560 square feet the above formula is also given as Q = CiA where A = area in acres).

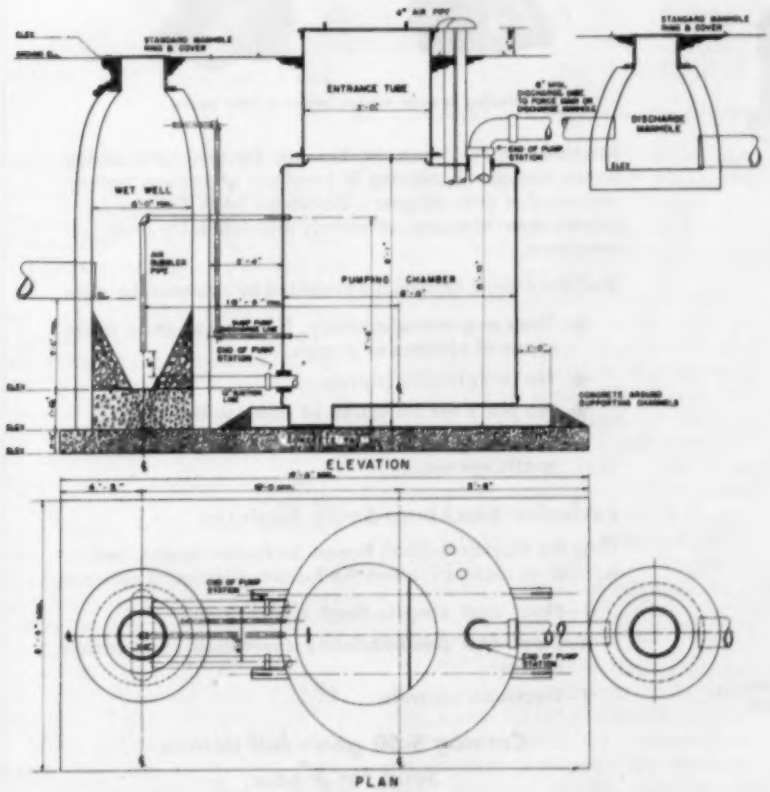

Fig. 1—DESIGN of factory-built underground sewage pump station

BLACKBURN-SMITH MFG. CO., INC.

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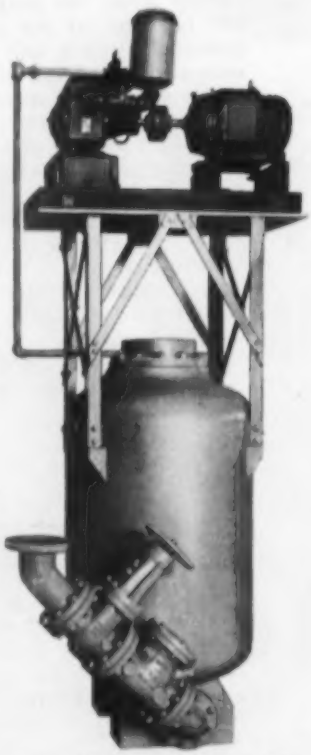
PNEUMATIC SEWAGE EJECTORS

The Modern, Efficient Way to Lift Sewage

30 to 500 gpm single and twin units for discharge heads up to 150 ft.

Duplex Sewage Ejector, showing inlet piping.



Compact ejector system having motor compressor assembly and all controls in one "packaged" unit.

Blackburn-Smith Pneumatic Sewage Ejectors have ended screen and pump cleaning in hundreds of sewage booster stations. For over 60 years, Blackburn-Smith Ejectors have proved their economy, efficiency, and reliability under all conditions.

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- ★ **No worry over operation in water with all-pneumatic system.**

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Only the Blackburn-Smith Pneumatic Ejector System, with or without air receivers, offers the following choice of controls:

1—Float and electric float switch;

2—Float and pneumatically controlled snap-action valve;

3—Electrode controls.

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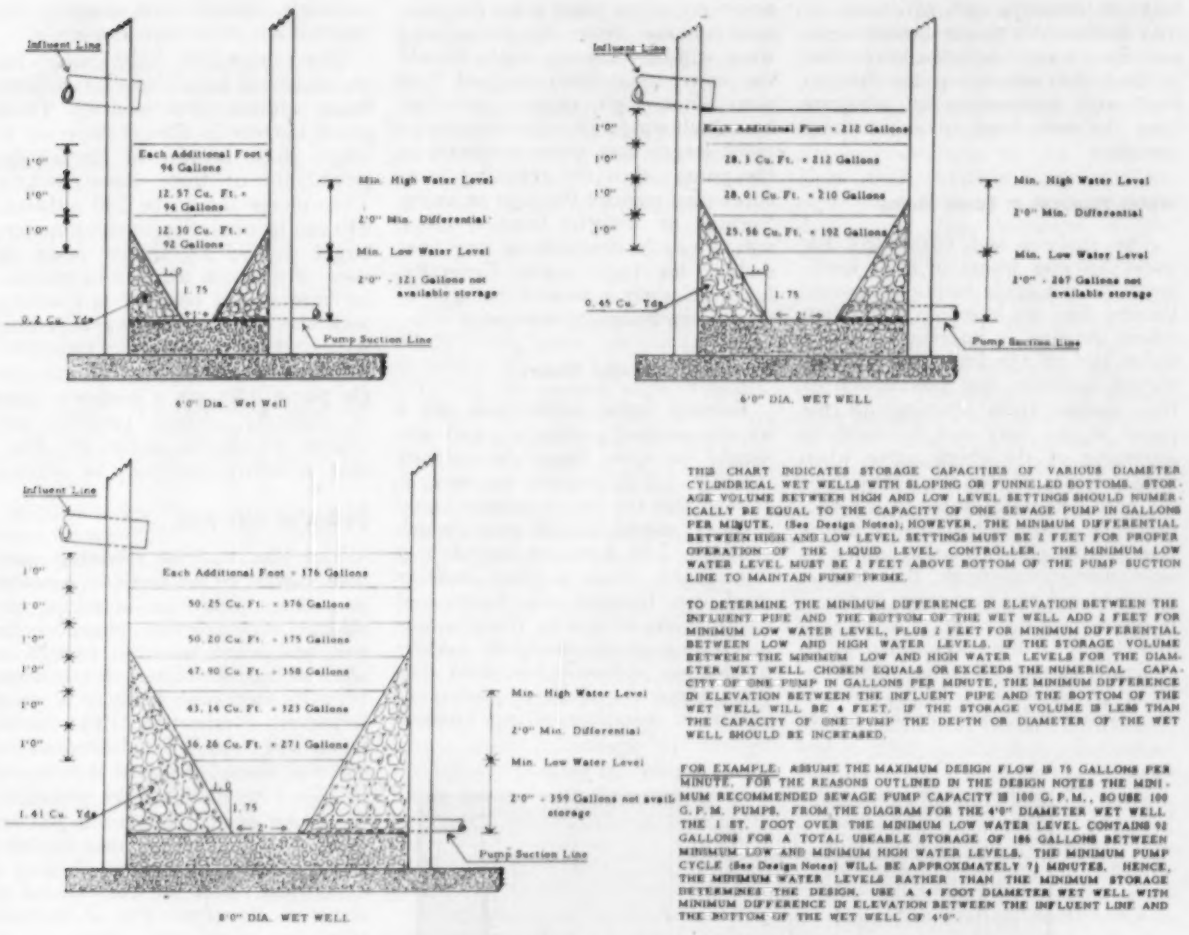

Influent Line
Each Additional Foot = 94 Gallons
12.57 Cu. Ft. = 94 Gallons
12.30 Cu. Ft. = 92 Gallons
Min. High Water Level
2'0" Min. Differential
Min. Low Water Level
2'0" - 121 Gallons not available storage
0.4 Cu. Yds.
Pump Suction Line
4'0" Dia. Wet Well
Each Additional Foot = 212 Gallons
28.3 Cu. Ft. = 212 Gallons
28.01 Cu. Ft. = 210 Gallons
25.56 Cu. Ft. = 192 Gallons
2'0" - 267 Gallons not available storage
0.45 Cu. Yds.
6'0" DIA. WET WELL
Each Additional Foot = 376 Gallons
50.25 Cu. Ft. = 376 Gallons
50.20 Cu. Ft. = 375 Gallons
47.90 Cu. Ft. = 358 Gallons
43.14 Cu. Ft. = 323 Gallons
36.26 Cu. Ft. = 271 Gallons
2'0" - 359 Gallons not avail. storage
1.41 Cu. Yds.
8'0" DIA. WET WELL

THIS CHART INDICATES STORAGE CAPACITIES OF VARIOUS DIAMETER CYLINDRICAL WET WELLS WITH SLOPING OR FUNNELED BOTTOMS. STORAGE VOLUME BETWEEN HIGH AND LOW LEVEL SETTINGS SHOULD NUMERICALLY BE EQUAL TO THE CAPACITY OF ONE SEWAGE PUMP IN GALLONS PER MINUTE. (See Design Notes); HOWEVER, THE MINIMUM DIFFERENTIAL BETWEEN HIGH AND LOW LEVEL SETTINGS MUST BE 2 FEET FOR PROPER OPERATION OF THE LIQUID LEVEL CONTROLLER. THE MINIMUM LOW WATER LEVEL MUST BE 2 FEET ABOVE BOTTOM OF THE PUMP SUCTION LINE TO MAINTAIN PUMP PRIME.

TO DETERMINE THE MINIMUM DIFFERENCE IN ELEVATION BETWEEN THE INFLUENT PIPE AND THE BOTTOM OF THE WET WELL ADD 2 FEET FOR MINIMUM LOW WATER LEVEL, PLUS 2 FEET FOR MINIMUM DIFFERENTIAL BETWEEN LOW AND HIGH WATER LEVELS. IF THE STORAGE VOLUME BETWEEN THE MINIMUM LOW AND HIGH WATER LEVELS FOR THE DIAMETER WET WELL CHOSEN EQUALS OR EXCEEDS THE NUMERICAL CAPACITY OF ONE PUMP IN GALLONS PER MINUTE, THE MINIMUM DIFFERENCE IN ELEVATION BETWEEN THE INFLUENT PIPE AND THE BOTTOM OF THE WET WELL WILL BE 4 FEET. IF THE STORAGE VOLUME IS LESS THAN THE CAPACITY OF ONE PUMP THE DEPTH OR DIAMETER OF THE WET WELL SHOULD BE INCREASED.

FOR EXAMPLE: ASSUME THE MAXIMUM DESIGN FLOW IS 75 GALLONS PER MINUTE. FOR THE REASONS OUTLINED IN THE DESIGN NOTES THE MINIMUM RECOMMENDED SEWAGE PUMP CAPACITY IS 100 G. P. M., SO USE 100 G. P. M. PUMPS. FROM THE DIAGRAM FOR THE 4'0" DIAMETER WET WELL THE 1 FT. FOOT OVER THE MINIMUM LOW WATER LEVEL CONTAINS 92 GALLONS FOR A TOTAL USEABLE STORAGE OF 186 GALLONS BETWEEN MINIMUM LOW AND MINIMUM HIGH WATER LEVELS. THE MINIMUM PUMP CYCLE (See Design Notes) WILL BE APPROXIMATELY 7½ MINUTES. HENCE, THE MINIMUM WATER LEVELS RATHER THAN THE MINIMUM STORAGE DETERMINES THE DESIGN. USE A 4 FOOT DIAMETER WET WELL WITH MINIMUM DIFFERENCE IN ELEVATION BETWEEN THE INFLUENT LINE AND THE BOTTOM OF THE WET WELL OF 4'0".

Fig. 2—CHART of storage capacities for wet wells

Determination of Pumping Head

It is important to make an accurate determination of the pumping head. The Fairbanks-Morse bladeless sewage pump normally furnished has the advantage of a much steeper head-capacity curve than conventional sewage pumps. Nevertheless, any appreciable error in head calculation will result in a variation of capacity of equal or greater magnitude. For small capacities a 10 per cent error in head will commonly result in over a 25 per cent increase or decrease in capacity. It is also important to remember that sewage pumps bought for small capacities, say 100 gpm, are operating very close to their shut-off (or maximum) head. Thus, it is particularly important to determine accurately the static lift. The use of an engineer's level is recommended.

The total dynamic head (TDH) is the sum of the following:

1. *Static lift,* which is the vertical distance from the water level (generally the low water level) in the sump or wet well to the water surface at the outlet of the force main.

2. *Pipe friction* in the suction and discharge lines. (Consult charts for converting valves and fittings into equivalent lengths of straight pipe, and for determining friction loss for various sizes of pipes.)

3. *Velocity head* ($V^2/2g$) which is the energy possessed by the water because it is in motion. For velocity of 8 ft per sec the velocity head amounts to 1.0 ft. Quite commonly this factor is small compared with the total head. Since force mains commonly discharge into a gravity tile sewer through an open transition channel in the bottom of the connecting manhole, most of the velocity head is recovered. As a result, it is frequently omitted from the head calculations.

Force Mains and Suction Line Design

If the pipe line is too small, excessive friction losses will result. Also, excessive velocities will accentuate any difficulties with water hammer or surge problems since the maximum pressure so developed varies directly with the initial velocity. (See the section on "Water Hammer.")

If the pipe line is too large it will cost too much. For handling sewage a minimum velocity of 2.5 ft per sec is required to prevent solids from depositing in the bottom of the pipe. Since most house connections are 4 in., both suction and discharge lines should be 4 in. minimum.

It will frequently be found that a pipe size adequate for one pump alone will deliver little extra sewage with the second pump also in service. This is not too important since the pump sizes are normally selected so one pump can handle the maximum flow.

Sometimes two discharge lines are provided; one to route the sewage to the treatment plant, another to some stream or ditch for emergency use, or for use during periods when adequate stream flow exists for disposal by dilution. When two force mains are provided a careful check of operating head conditions for both routes is necessary to insure that the pumps will operate satisfactorily for either. The use of a pump with a steep head capacity characteristic, such as the Fairbanks-Morse bladeless pump,

helps to minimize such difficulties. It may be desirable to use a smaller size pipe for the route with the lower static head thus increasing the friction head and maintaining an adequate total dynamic head to avoid noisy operation.

Water Hammer in Force Mains

The analysis and formulas for water hammer found in most handbooks do not apply to pump stations because they are based on a situation where the flow is interrupted at the outlet end of the line. For a pump station, however, the interruption of flow results from shutting off the pump at the inlet end followed by slamming of the check valve when flow reverses. When the pump stops the entire mass of water in the suction line, pump and discharge line is free to continue in motion under its own momentum until the column comes to rest and then starts to travel in the reverse direction. It is the sudden closing of the check valve which generally causes water hammer trouble in pump stations. If the valve is of a type which closes quickly before any reverse flow takes place the pressure increase from the returning wave will be relatively small. Should the valve stick, however, and then slam after high reverse velocities have built up (such velocities can be much larger than those produced by the pump) then the resulting pressures may rupture the pipe or valve. Springs or weight loaded check valves may be desirable on long lines and/or for high heads. Generally, however, water hammer is not a problem in sewage pump stations.

Size of Pumps and Motors

Because house connections are 4 in., the smallest pump (or pipe) size should be 4 in. Since the velocity must be 2.5 ft per sec or more, it follows that the very minimum pump capacity should be 100 gpm (which produces 2.55 feet per second in a 4-in. pipe). Since a 3-in. diameter solid can traverse the bends and rough joints of a 4-in. tile pipe line the sewage pump should be capable of handling at least a 3-in. solid. The pump should be of a type proven superior in handling stringy fibrous materials, because most clogging difficulties are from such materials.

Motors should be large enough for the increased horsepower at reduced heads without overloading. Three phase current is always superior to single phase because of greater dependability of three phase motors. The voltage should be 220 although 440 can be used. Single phase motors larger than 5 hp should never be used. For single phase jobs particular care should be used in checking with the power company regarding wire sizes and transformer capacities. Low voltages at the end of long single phase lines are a common cause of difficulty. Where possible, two sources of electric power are desirable to insure continuity of service.

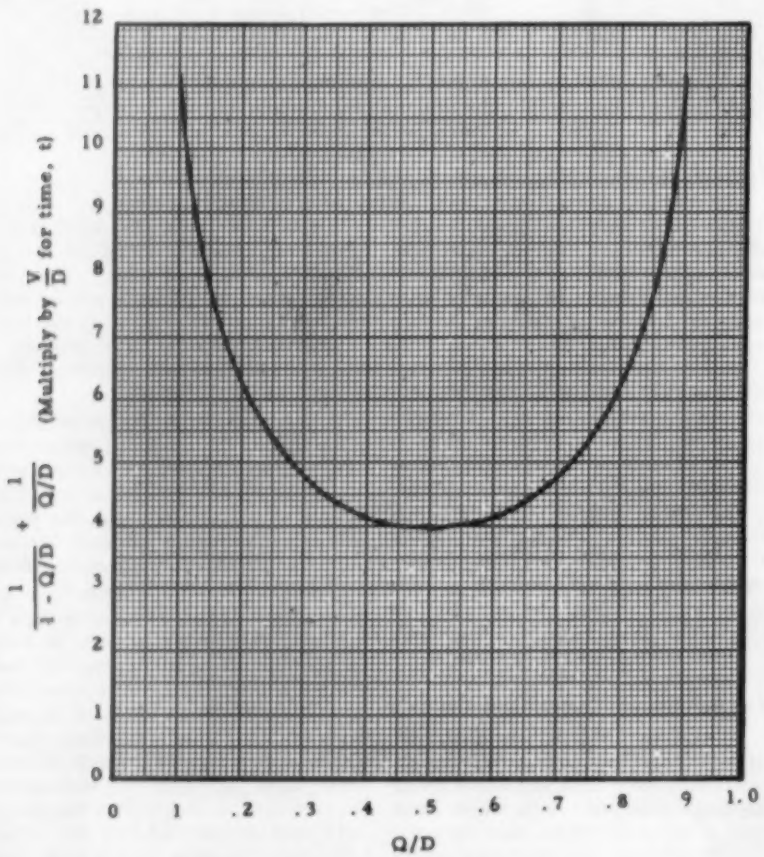


Fig. 3—CURVE for determining pump operating cycle

Design of Wet Well

The Wet Well or receiving manhole should be as small as possible to prevent septic action during periods of very low flow. However, the wet well must be large enough to allow at least 3 to 5 minutes to elapse between successive starts of a pump to prevent overheating of the electric motor and control. The bottom of the wet well should be sloped as indicated in Fig. 1 to eliminate the possibility of sewage solids settling out and becoming septic. The volumes resulting from the flat slopes intersecting a cylindrical sump are complicated to compute, therefore, Fig. 2 shows a tabulation of storage volumes for 4, 6 and 8 ft diameter wet wells so constructed.

Normally, a wet well is constructed of brick or of curved concrete blocks of the type available for either 4 or 6 ft manholes. The blocks for 6 ft manholes can be used very successfully to build an 8 ft diameter wet well by opening up the inner joints. The inner surfaces of the concrete blocks should be parged with cement mortar and given a bituminous coating to protect the concrete from acids in the sewage. See Fig. 1 for the general construction of the wet well and its relationship to the pump station. Note that the elevation of the bottom of the wet well is determined by the elevation of the invert of the lowest sewer flowing into the wet well *and* by the vertical distance below the invert required for adequate storage to permit a 4 minute operating cycle.

It can be demonstrated mathematically that the length of the operating cycle has a parabolic variation and that the shortest operating cycle occurs when sewage is flowing into the wet well at one-half of rated pump capacity.

If D = Rated pump delivery in gpm
V = Storage volume between high and low levels in gal
Q = Inflow to wet well in gpm
t = Total time between successive pump starts (operating cycle)

$$\text{then } t = \frac{V}{D-Q} + \frac{V}{Q}$$

$$\text{and } t = \frac{V}{D}\left[\frac{1}{1-\frac{Q}{D}} + \frac{1}{\frac{Q}{D}}\right]$$

Where V and D are constant for any particular installation.

To obtain the operating cycle in minutes for a particular installation multiply the vertical reading from the curve in Fig. 3 by V/D.

If the storage (V) equals the rated pump capacity (D) and if sewage is flowing into the clear well at one-half the pump capacity (Q/D = 0.5), then it would take two minutes to pump from the high level to the low level. It would take two more minutes to refill the wet well to the high level. Thus, the cycle is four minutes. As the above curve shows, this is the *minimum* cycle. For any other combination of inflow and pumping rates the cycle is longer. It is interesting to note from the above curve, however, that for such wide variations of inflow as 0.2D to 0.8D the operating cycle only varies from 4 to 6¼ minutes.

Since a 4 minute cycle is a reasonable minimum for reasonable electrical control life it follows that: *The minimum storage required in gallons is numerically equal to the pump rated capacity in gallons per minute.* An examination of Fig. 2 will show that a standard four foot diameter manhole is big enough for most small systems because only 100 gallons of storage is required for the minimum size (100 gpm) pump recommended. Note that the figure is only the minimum and more storage is desirable when available at little or no additional cost. Actually it may *not* be possible to use the minimum so determined because there must be at least a two foot differential between the high level and low level settings of the low level pump. The high level pump settings normally overlap the low level range, being at least 6 inches to 1 foot higher in each case.

It is impractical to provide storage in the wet well for prolonged power outages or excessive sewage flows. It is much cheaper and more dependable to select each pump to handle maximum flow. Where possible a gravity overflow line from the wet well to some water course is a very desirable feature. Such an overflow line automatically protects basements from flooding or prevents other nuisances during power failures. If the possibility exists that high water from such a water course can back up into the wet well, a flap gate or check valve should be incorporated in the line.

Summary

For a satisfactory pumping station the following points should be borne in mind:

1. Use two pumps, each of which is adequate for maximum flow.
2. Use an automatic alternator to distribute the wear on the motors and to keep the motor windings dry by frequent operation.
3. Provide double mechanical seals on the pumps in place of stuffing boxes, with clean sealing fluid between the seal surfaces at a pressure higher than the maximum sewage pressure. While many manufacturers make good sewage pumps, *no* sewage pumps have a completely satisfactory packing box. All sewage contains gritty solids. Leakage of sewage through the packing box permits such solids to cut out the packing and more important yet, the shaft or shaft sleeve next to the packing. After the shaft or sleeve wears the leakage increases.

Many attempts have been made to prevent leakage of sewage through the box by placing a lantern ring between several layers of packing and by then introducing clean water or lubricant under pressure higher than the sewage pressure. Such efforts result in improvement but not in a satisfactory solution to the problem. Even when handling clean water or clean oil or clean grease the packing *does wear!* The clearances on the shaft increase and leakage results with consequent accelerated wear!

Generally, the pressure or volume of sealing fluid is not adequate to maintain a pressure higher than the sewage pressure so sewage leaks up the shaft, mingles with the sealing fluid and passes out into the station. If higher seal fluid pressure is provided to prevent this, excessive seal fluid is used at high expense and with the seal fluid leaking into the station. The fact all of the seal fluid has been used up may not be discovered immediately—and excessive wear will result. This leakage of smelly, corrosive sewage is very undesirable in any pump station.

The double mechanical seal, in contrast, is almost completely free from leakage. One seal surface is of stainless steel or similar hard, corrosion-free material. The other is of a self-lubricating material such as carbon. Two such combinations are provided with seal fluid under pressure between them for cooling and lubrication. If a bubbler system for level determination is used, then the same small air compressor which operates

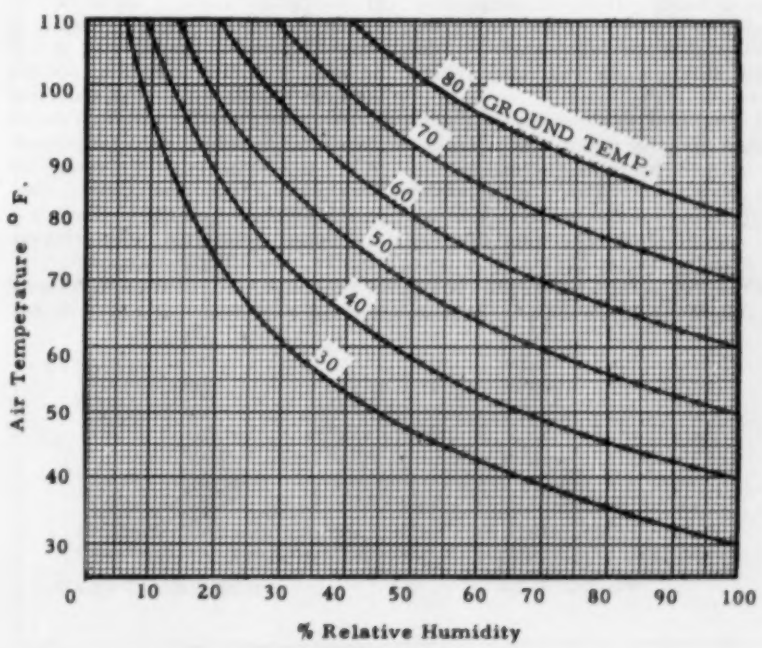


Fig. 4—CURVES for predicting condensation

the bubbler system can also place air pressure on top of the seal fluid in its reservoir. The top of the reservoir thus becomes the air storage tank and any condensation caused by the compressor is trapped therein. The air pressure should be 5 psi minimum in excess of the maximum sewage pressure.

Any leakage is of clean, non-abrasive sealing fluid cut into the sewage or out into the air. For a properly installed seal in good condition such leakage is practically nothing. As wear of the seal takes place, the seal automatically takes up the wear as the spring loaded surfaces move together.

The sealing fluid in the Smith & Loveless system is mostly water with a small amount of emulsified oil added for corrosion protection. The reservoir may be refilled, when needed, with clean water. A gauge glass shows the fluid level at a glance. Any normal leakage into the station is so small that the dehumidifier will evaporate it and dispose of it.

To protect the seal surface next to the sewage a check valve is provided in the fluid line next to the seal. This keeps sewage from being forced into the seal chamber if the air pressure fails or if the pump is throttled, thus raising the pump pressure above the seal fluid pressure.

The use of mechanical seals installed in this manner keeps the pump chamber clean and dry.

4. Provide a dependable sump pump with maximum protection against flooding from the sump pump discharge line. If possible, carry the discharge above high water in the wet well. Use two check valves if this cannot be done.

5. Provide an automatic control system for the pump which cannot be clogged by grease accumulation (as can a float system), or cannot be clogged by sewage solids or debris (as can a compression pipe type of air actuated control). This latter type has the further disadvantage of being very hard to adjust and to keep in adjustment because of the need for a delay cycle to recharge the compression pipe on each cycle to prevent water logging.

Experience has shown that the most dependable system is the air-bubbler system. This system includes a compact air compressor with built-in pressure control and storage tank. The air goes through a needle valve with automatic differential pressure regulator to insure constant flow by providing a constant pressure differential on the orifice. A visual flow meter provides a quick visual check on this air flow. The air discharges through a corrosion resistant line into the sewage below the low water level. The amount of submergence of the end of the line determines the back pressure. This back pressure is measured by sensitive pressure switches of the Bourdon tube type with magnetically actuated mercury tubes. The constant flow of air out of the end of the bubbler line keeps sewage from clogging the line. While sensitive, it is easy to adjust with completely independent high and low level adjustments for each pump.

6. Control Humidity—Any underground structure, whether of concrete or steel, in most parts of the country is subject to condensation problems during part of the year. From about 6 feet underground down to the maximum depth practical for pump stations of this type, the ground temperature will be almost constant the year around. In the vicinity of Kansas City the ground temperature is about 52° F. When the outside air temperature is above the ground temperature it will be cooled when it comes in contact with the station walls. The reduction in temperature will raise the relative humidity, possibly to 100 percent. When the humidity of the cooled air does reach 100 per cent then condensation will occur on the cold surface, and the temperature at which this occurs is termed the "dew point".

Figure 4, together with local weather information and ground temperature, will enable the engineer to determine the seriousness of the problem. If the air temperature and the relative humidity intersect above the ground temperature line, then condensation will take place on the floor and walls of any underground structure.

In most parts of the country it will be necessary to combat humidity introduced with the outside air. In all parts of the country mechanical pump shaft seals are needed to keep out excess humidity from shaft leakage. A refrigeration type dehumidifier should be mounted in the air inlet duct so arranged that air is drawn through the dehumidifier from the outside whenever a pump is running. This fresh air is to remove motor heat and to ventilate the station periodically.

When no pumps are running, the air within the station should be recirculated automatically to dehumidify it before it cools. The dry air will absorb any moisture in the sump. Such dehumidifiers with sealed motor-compressor units are very dependable and long lived. The dehumidifier makes a properly built underground pump station superior to any other construction because of uniform temperature (from the ground) and uniform dryness.

7. Protect the steel structure inside and out against corrosion. Experience indicates that a sacrificial protective coating such as Zincilate (which is equivalent to galvanizing) provides the best base for the outside. An additional double coat of inert insulating material such as coal tar base paint should be used as a protection against chemically active soil. As an added insurance magnesium anodes or a DC rectifier system should be used for cathodic protection. Sufficient coatings and cathodic protection are installed on Smith & Loveless underground pumping stations to protect the structure from corrosion in average soil for 50 years minimum.

Laying and Jointing Sewer Pipes

by FRED C. PALMER

Engineer, Nat'l Sewer Pipe Co., Ltd., Toronto, Ont.

THE question of preventing roots from entering sewer pipes and the annual cost for removing the same, gives considerable concern to sewer departments.

This paper has been drawn from practical experience and experiments, carried out over years, to produce a root-proof and leak-proof joint.

It is also intended to explain, without scientific data and complicated formula, so that the workman, the pipe layer or contractor may be conversant with the many reasons why joints may be defective. The writer is conversant with the many inconveniences and difficulties which confront the contractor and his pipe layer—wet and muddy trenches, threatening storms and cave-in, all of which tend to make difficult the workmanship being carried out.

Roots

Roots will not grow through solid concrete or a solid cement joint, unless there is an opening. They will grow through the very finest hair crack. Roots will not grow through a properly made compound (bitumen joint), but will find their way through a blow-hole or improperly heated compound.

At the tip of a root is a very fine tendril, finer than a human hair. As this tendril grows and reaches a sewer pipe joint, it turns and glides over or under solids, but reaching the finest opening, it enters. Upon entering, the movement of air and flow of sewage draws it in and the warmth of the sewage and its fertilizing properties induce rapid growth. Roots in sewers can be temporarily removed by tools and machines and in some cases their growth can be retarded by the use of chemicals, but they cannot be permanently removed without re-constructing the sewer.

It is not the intention of the writer to deal with the removal of roots from sewers, but rather to suggest means and best methods to prevent their entrance.

Some Types of Joints

The necessity for secure joints is no new problem. Forty years ago engineers introduced the following joints, as shown. These joints are all cast upon the pipes by the pipe manufacturers. (Fig. 1)

Duckett's Patent Stanford Joint (a)

On the spigot and in the socket is cast a bituminous material gradually tapered. Before fitting the pipes together the joints are greased with a mixture of resin and Russian tallow. This makes a tight joint, but it is advisable to finish it off with a seal of cement smoothly trowelled.

Doulton Patent Joint (b)

This is similar to the Stanford with less bitumen and a heavier cement seal. The manufacturer's claims for this joint—imperishable, flexible and can be laid under water.

Tyndale's Patent Double Seal Joint (c)

The convex ring on the spigots makes possible a tighter fit than tapers. The socket of the pipe is deeper and undercut to permit an effective seal with cement.

Button's Patent Joint (d)

These rings are cast with annular grooves. When the pipes are fitted together a grout cement is poured in, which flows and sets between the bitumen rings.

Hassel's Joint (e)

Two cast bitumen rings and two perforations in the socket about three inches apart. After the pipes are fitted together a grout cement is poured into one of the perforations and pouring continues until the grout comes up into the other perforation.

Sykes' Patent Joint (f)

The pipe for this joint is especially manufactured with a flange near the spigot end. The bitumen is moulded in a screw-like thread. Before fitting together a special adhesive cement is spread over the bitumen threads and the pipes are then screwed together. This gives an exceptionally tight joint.

The foregoing joints are shown and described primarily to point out that *expense in jointing becomes secondary to efficiency.*

There are no special joints cast or moulded on sewer pipes by pipe manufacturers in Canada, and the writer is not aware of any joints cast or moulded on sewer pipes in the United States by pipe manufacturers, excepting perhaps special acidware pipe.

There are patent joints, mostly manufactured by chemical companies. These include Patent Rubber Rings, Pre-Cast Compound Joints and Compound for Pouring Joints. These joints require skill and care in their making.

The Rubber or Rubberoid Ring is manfactured to fit the size of pipe required. A cut-back oil is used to aid adhesion, the socket is painted with the cut-back and the ring placed in the socket, then the ring is painted with the cut-back on the inside and on the outside of the spigot and the pipe fitted home. With reasonable care, this is a good joint, but sewer pipes vary in dimensions, such as inside width of socket and outside width of spigot. The variation may be according to the dies of the manufacturer or shrinkage in burning the pipes.

In this, as in any other pre-cast joint, it is necessary to ensure that the pipes used are adaptable to the joint. Some manufacturers supply deeper and wider sockets than others and again some manufacture thicker bodied pipes; and, in burning, sewer pipes vary in shrinkage.

Compound for Either Pre-Cast or Poured Joints

Without going into detail of chemical formulae, Bitumen Jointing Compound consists of approximately 50 per cent asphalt oils and 50 per cent filler, which may be marble dust, slate dust or other aggregate. The heavier the filler, the more difficult it is to hold in suspension; consequently the necessity for repeated stirring during heating and always immediately before dipping out for pouring is evident.

If the compound is left unstirred, the filler sinks to the bottom and on a hot fire will, with the asphalt at the bottom, burn, leaving a residue like coke in the bottom of the pot.

If the compound is poured without having been stirred, the joint will be defective. It will develop blow-holes and through being poured with insufficient filler will overshrink.

When bitumen compound is first used, the pouring temperature as recommended by the manufacturer should be checked with a thermometer so that the workman can become conversant with the appearance and the consistency of the material as it reaches the pouring temperature. Having observed this, he will not need to continuously use the thermometer.

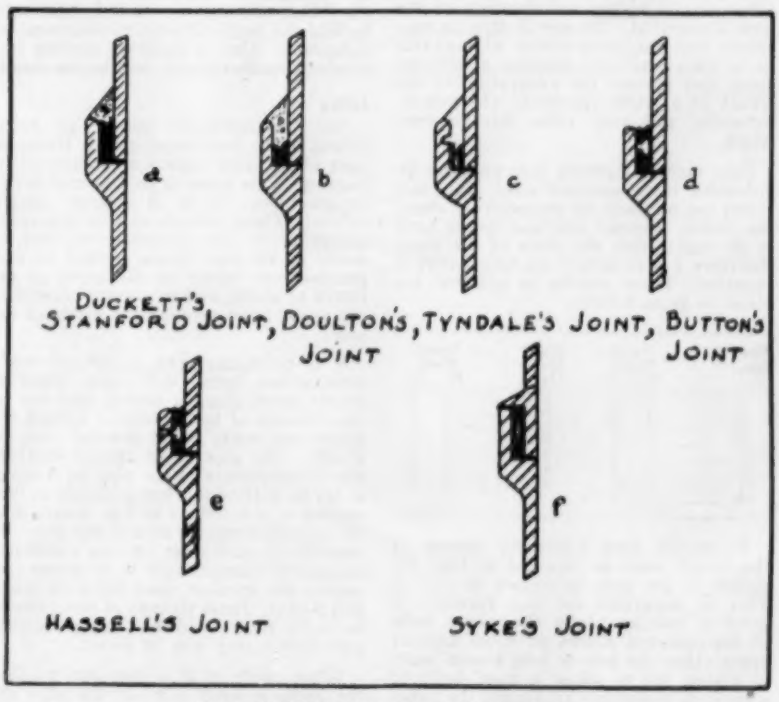


Fig. 1. SPECIAL joints patented by engineers

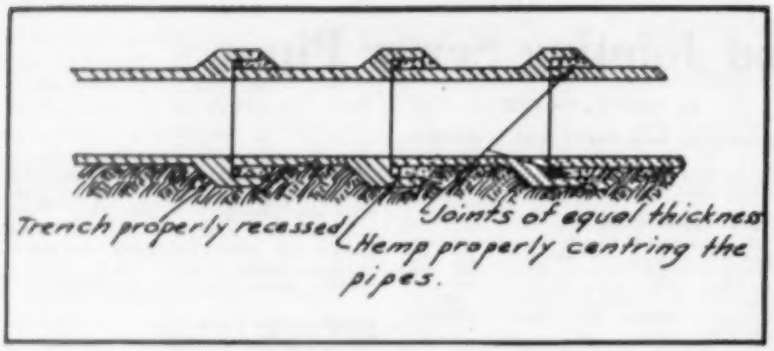


Fig. 2. Correct Sewer Pipe Laying and Jointing

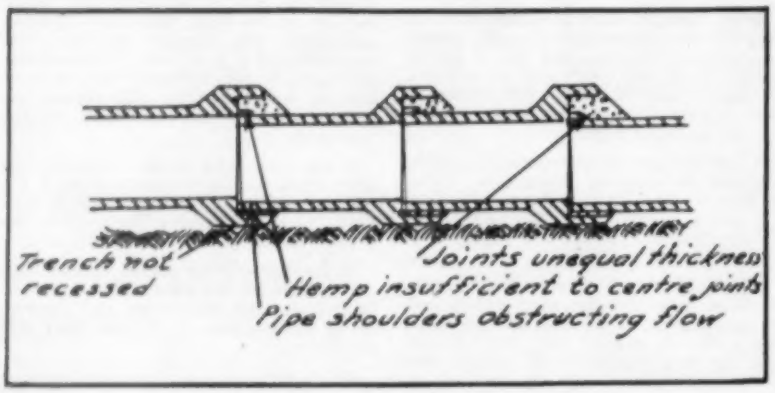


Fig. 3. DEFECTIVE sewer pipe laying and jointing

The Trench

Regardless of the fact that the suggested or specified width of trench receives consideration with respect to load on the pipes, a width sufficient to allow proper laying and jointing of the pipe is essential. The use of digging machines and the composition of material to be excavated and weather conditions sometimes prevent the excavating of the trench at a width specified. The trench, naturally, will vary either less or over width.

Four inch to eighteen inch pipe can be straddled by a medium sized man and joints can be made all around from above the socket. Beyond that size, joints have to be made from the sides of the pipe; therefore a satisfactory working width is required. These widths in practice are found to be as follows:

Pipe Size, In.	Trench Width, Ft.	Trench Width, In.	Pipe Size, In.	Trench Width, Ft.	Trench Width, In.
4	1	6	21	3	9
6	1	9	24	4	0
8	2	0	27	4	4
9	2	0	30	4	9
10	2	3	33	5	0
12	2	6	36	5	6
15	2	10	42	6	3
18	3	3			

To ensure good joints the bottom of the trench must be recessed to take the socket of the pipe, as shown in Fig. 2. This is important for two reasons: it gives a bearing along the whole body of the pipe and allows an equal annular space (after the jute or long strand hemp is placed in) to allow a good body of cement or compound all around the jointing space. (Fig. 2)

Laying and Jointing

If the pipe sockets are not recessed, the result will be as shown in Fig. 3. They will be bearing only on socket to socket and the annular space at the bottom of the socket will not be centered sufficiently to hold the required amount of cement or compound. Also, a shoulder causing obstruction as also shown, will be the result.

Juting

Jute, commercially known as Long Strand M.O. (minimum oiled) Hemp is used either with cement or compound in jointing. This hemp is sold in rope form, ranging from 10 to 35 strands loosely twisted. These strands can be separated according to the thickness required to center up the pipe. Hemp is used for two purposes—to center up the pipes as referred to above, and to prevent cement or compound from entering the inside of the pipes.

It is quite improper to see on sewer construction jobs, the pipes standing socket down along a trench, and one or two strands of hemp twisted around the spigot end ready to be lowered into the trench. The pipe layer should measure the circumference of the pipe he is about to lay by putting this hemp around it, then cutting it in lengths 4 to 6 in. longer than the outside circumference of the pipe. He should pull apart from the rope a sufficient number of strands to fill in thickness (not depth) the annular space between spigot and socket. These strands of hemp should be in the trench with him, not put on the pipe before they are let down.

When ready to fit a pipe into another, the hemp is used to guide the pipe into the socket and is carried into the bottom of the socket with it. The top and sides are then rammed in with a piece of hardwood or caulking tool. It is sometimes specified to dip the hemp in a grout cement first. This does improve the joint, when making cement joints.

The pipe layer holds the strands of hemp rope in one hand and puts the rope across his thigh; he rolls it with the palm of his other hand, which twists the strands together, then holding both ends with one hand he can dip his hemp. Then with an end in each hand he places it under the spigot and guides the pipe into the socket.

Compound Pouring

In pouring compound joints considerable time is saved by ensuring that the running rope is secure and tight in or against the socket, as the liquid when poured is liable to run out of the space. It is well to plaster trench clay around the running rope where it fits against the socket.

The running rope is asbestos, square or round. Round is preferable for sewer pipe. Before using, the rope should be well rubbed with moist clay or graphite to prevent the compound sticking to it.

Compound should be poured slowly in a steady stream and continuously if possible. The weather condition (temperature) should be observed. It is likely in cold weather and particularly with 15 inch pipe and over that the compound will set before flowing to the bottom of the pipe. In this condition, it is well to thaw out or warm the spigots with a lighted rag and kerosene.

Cement Joints

When making cement joints in warm or hot weather, the spigot of the pipe or the whole pipe, should be well wetted, otherwise the moisture in the cement at the joint will be absorbed by the pipe and sufficient moisture will not remain in the jointing cement to allow it to set without cracking.

If neat cement for jointing is used, the joint must be kept moist while setting, particularly in shallow dry trenches.

Providing the pipes when laid and jointed are not immediately disturbed by common faults, such as walking on the pipes, climbing in and out of the trench on the pipes, placing a heavy cement pail roughly on pipe where it lodges on the shoulder of the pipe and leans on the side of the trench, immediate backfilling, knocking joints to pieces and disturbing joints newly made or removing shoring too hastily, the writer has obtained best results from the following:

One part portland cement, two and one-half parts clean, sharp sand. Mix dry, then add sufficient water to dampen, then mix (dampen only). Allow to stand forty-five minutes, then add sufficient water to bring to the consistency for good trowelling. This mix and the time allowed to prehydrate with moisture, eliminates shrinkage and gives excellent adhesion.

Recommended Joint

The writer prefers and recommends the following joint, favorable under any conditions, and as near fool-proof as jointing can possibly be. Use a good jointing compound, such as "G-K," or equal. Place a board or plank on the ground near the melting pot (Fig. 4) and measure the width of the annular space between the spigot and the socket of the size of pipes to be jointed. Place two boards upon the

board or plank already placed and space the two top boards the width of the annular space to be filled and have the two top boards thick enough to be two-thirds the depth of the socket of the pipe, or space your top boards at a distance equal to two-thirds the depth of the socket and as thick as the width, either way will do.

Put a good coat of wash (composed of whitening and water creamy in consistency) with a brush between the space of the boards. This is to keep the compound from sticking to the boards. Put a plug of trench clay in the boards at each end or at a distance equal to the circumference of the pipe or pour several lengths at one pour.

Pour the compound steadily backwards and forwards into the opening, leave it ten minutes to properly set. When one side board is taken away a compound strip, rubber like, has been made.

In warm weather this will be found quite flexible; in cold weather the rings can be kept flexible by laying on a board near the heating pot. Fit it into the joint space and caulk the joint with a piece of hardwood or caulking tool, then cement the balance of the annular space. This will give a waterproof and root-proof joint, with a minimum of labor.

In very wet trenches it is suggested that after caulking in the first ring a second ring be caulked in and the cement eliminated.

The importance of laying and jointing sewer pipes has been recognized by the government of the Province of Ontario, which last year passed a bill enabling all towns and cities to license sewer and drain layers. Men doing this work should be classed as skilled labor. They should be made conversant with the engineers' specifications and the importance of proper laying and jointing should be conveyed to them personally by the engineer or inspector.

They should be made to feel that the importance of their work is appreciated and confidence is placed in their ability to do their best under sometimes very difficult circumstances.

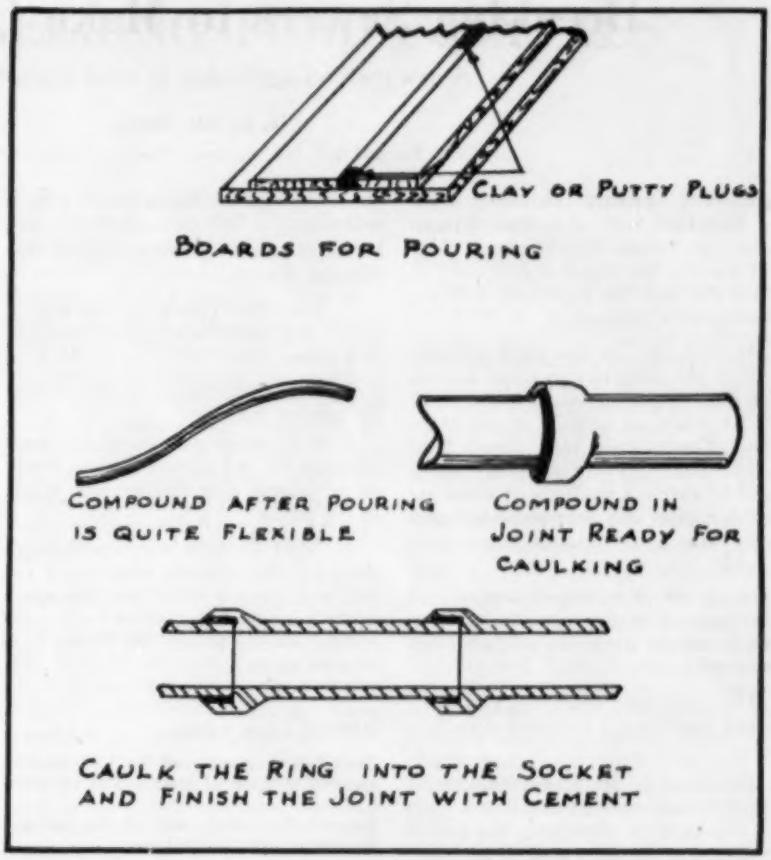

CLAY OR PUTTY PLUGS
BOARDS FOR POURING
COMPOUND AFTER POURING IS QUITE FLEXIBLE
COMPOUND IN JOINT READY FOR CAULKING
CAULK THE RING INTO THE SOCKET AND FINISH THE JOINT WITH CEMENT

Fig. 4. COMBINATION Compound and Cement Joint

Definite and complete specifications by the engineer and co-operation of the contractor and his pipe layer will eliminate root trouble and infiltration.

Breaking Sewers to Make Connections

A new method applicable to small diameter pipe

By H. WM. JEWELL

Chief, Res. and Dev., National Sewer Pipe Co., Toronto, Ont., Canada

SEWER systems frequently have been built without providing junctions for future development. Unfortunately, this makes it necessary to break through the pipe wall and cementing in a connection.

At best, this is not good practice and, in the long run, is more expensive than providing an adequate number of junctions at time of construction. Maintenance men report that many structures are seriously damaged by careless methods of breaking through pipe and that these connections are a continuous source of trouble.

In an effort to improve the practice, several maintenance men were canvassed and a number of their ideas were tried out.

The procedure discussed and illustrated here seems to merit consideration.

The idea is applicable principally to small diameter bell and spigot pipe. In this type of structure, the line is strongest at the joint and, in addition, it is easier and safer to knock off the bell section as illustrated, than to cut a hole through the pipe barrel.

Removal of the bell section allows access to the inside of the pipe at the junction of the two pipes. A small hole, large enough to insert a wrench or breaking tool as illustrated, can easily be chipped through at the end of the abutting pipes. The balance of the hole can be broken out with a wrench.

Some points of advantage to this method are:

1. The interception of the line is made at a point where there already is a joint.

2. The connection is at the strongest part of the line.

3. It is easier and safer to break through the bell section than to knock an additional hole through the barrel of the pipe.

4. After the hole is broken through the pipe, the adjacent sections of the bell and cement-filled annular space provide a supporting shoulder for the mortar sealing around the fitting (see bottom photo).

PHOTOS, top to bottom:

First—Before chipping off the bell, continue sounding until size of break is plainly marked.

Second—With chisel, chip off the bell and the cement under sounded area.

Third—Widen the area by undercutting cement and chipping down undercut area. Break through to inside of pipe where bell was removed.

Fourth—Use wrench for breaking pipe to enlarge the hole. Note supporting sections of bell.

Fifth—Fitting in position for cementing. The mortar will fill in between pipe and shoulder of fitting.

CARRYING CAPACITY OF SEWER PIPE—GALLONS PER MINUTE

(Based on "Hydraulic Tables" by Williams & Hazen)

Size, Inches	1" Fall in 100 Feet	2" Fall in 100 Feet	3" Fall in 100 Feet	6" Fall in 100 Feet	9" Fall in 100 Feet	12" Fall in 100 Feet	24" Fall in 100 Feet	36" Fall in 100 Feet
4	.....	.....	.....	.....	86	102	149	186
6	.....	.....	.....	204	256	297	269	534
8	.....	.....	.....	437	539	632	921	1143
9	.....	.....	.....	601	749	876	1272	1580
10	.....	.....	537	781	974	1138	1653	2055
12	.....	730	869	1264	1571	1835	2695	3345
15	.....	1242	1556	2275	2835	3300	4790	5950
18	.....	2030	2510	3670	4580	5340	7760	9665
24	2985	4325	5390	7810	9740	11380	16530	20550
27	4040	5875	7325	10690	13270	15520	22530	27850
30	5340	7760	8670	14080	17500	20450	29750	37150
36	8740	12600	15640	22700	28350	33000	47900	59500

IX—ENGINEERING FUNDAMENTALS

THE DESIGN, construction and operation of water or sewage works lies in the field of sanitary engineering. This field of endeavor is quite broad; no other branch of engineering requires a knowledge of so many fundamental and applied sciences.

Source of supply for water works involves hydrology, geology, and hydraulics. Construction of facilities involves civil engineering; flow of liquid involves hydraulic principles; treatment of water and sewage involves chemical engineering unit processes in structures utilizing mechanical equipment powered by electricity. Reactions in water and sewage treatment involve inorganic, colloidal and biological chemistry.

Among the fundamentals for which a sound knowledge is essential are the subjects of chemistry and bacteriology, hydraulics, and mathematics.

Chemistry and Bacteriology

All water and sewage works laboratories should have, in their libraries, a copy of the latest edition of "Standard Methods for the Examination of Water, Sewage and Industrial Wastes", published jointly by the APHA, AWWA and the FSIWA.

The AWWA "Manual of Water Quality and Treatment" contains chapters on the chemistry and bacteriology of water treatment and several textbooks discuss the chemistry of sewage treatment. A particularly useful reprint published by *Water & Sewage Works* is "The Chemistry of Water Treatment" by Dr. A. P. Black.

Hydraulics

Measurement of flow in both water and sewage treatment systems and plants is essential to the proper operation of each. This subject has been presented in several articles in this and previous editions of the Reference & Data issue. An excellent reprint on the subject has been published by *Water & Sewage Works*, titled "Practical Hydraulics" by Prof. Robt. W. Angus.

Mathematics

No plant manager or operator can carry on his work without the use of mathematics. While higher mathematics is useful in many calculations, the simpler branches of mathematics are essential. An excellent treatise titled "Elementary Mathematics" by Prof. Warren Eglof has been published by *Water & Sewage Works*.

Charts, Nomographs and Tables

It is often helpful to an operator to have available, charts, tables, nomographs and diagrams by which mathematical calculations can be simplified. In this following section of this Reference & Data Edition, there are a number of these charts, etc. dealing with the subjects of chemistry, hydraulics and mathematics. Additional charts and nomograms, etc. will be found in previous editions of the Reference & Data Edition of *Water & Sewage Works*.

Atmospheric Pressures & Barometric Readings at Various Altitudes

Altitude Ft.	Barometric Pressure Ins. of Mercury	Atmospheric Pressure Lbs. per sq.in.	Equivalent head of water in ft.	Boiling Point of Water°F.	Altitude Ft.	Barometric Pressure Ins. of Mercury	Atmospheric Pressure Lbs. per sq.in.	Equivalent head of water in ft.	Boiling Point of Water°F.
0	29.92	10.7	34.0	212.0	5000	24.89	12.2	28.2	202.9
500	29.38	14.4	33.3	211.1	5500	24.43	12.0	27.8	201.9
1000	28.86	14.2	32.8	210.2	6000	23.98	11.8	27.3	201.0
1500	28.33	13.9	32.2	209.3	6500	23.53	11.5	26.6	200.1
2000	27.82	13.7	31.7	208.4	7000	23.09	11.3	26.2	199.2
2500	27.31	13.4	31.0	207.4	7500	22.65	11.1	25.7	198.3
3000	26.81	13.2	30.5	206.5	8000	22.22	10.9	25.2	197.4
3500	26.32	12.9	29.8	205.6	8500	21.80	10.7	24.8	196.5
4000	25.84	12.7	29.4	204.7	9000	21.38	10.5	24.3	195.5
4500	25.36	12.4	28.7	203.8	10000	20.58	10.1	23.4	193.7

Alkalinity Equivalents

AMONG the mineral compounds present in natural waters, Calcium Carbonate is the most ubiquitous. Partly for this reason and partly because its molecular weight at the time, was thought to be exactly 100, this compound was chosen as the standard to be employed in the measurement of alkalinity and hardness.

With more accurate determination of atomic weights, the molecular weight of Calcium Carbonate is now assumed to be 100.08. Very obviously, tables earlier prepared under the assumption that the molecular weight was 100 will have a small and not entirely negligible error if the true weight be 100.08. The accompanying table, based upon the newer molecular weight of 100.08 for Calcium Carbonate, are arranged in such manner as to facilitate comparisons against other substances having different values of alkalinity. These values are presented as being more accurate than those appearing in earlier tables computed on the old 100 molecular weight value assumed for Calcium Carbonate.

A brief explanation of how the tables may be used follows.

In the sixth column, sixth line, the unity of Calcium Carbonate may be compared directly against every other factor in the column. For instance, one part of alkalinity, due to Calcium Carbonate, is the exact equivalent, in alkalinity value, to that which would be imparted by 1.6196 of Calcium Bicarbonate; 0.7403 of Calcium Hydroxide; 0.8424 of Magnesium Carbonate; 1.0590 of Sodium Carbonate (dehydrated), etc.

Along the line, right or left, a different comparison may be made. The molecular weight, for instance, of Calcium Bicarbonate, is in excess of that of Calcium Carbonate. Therefore, it takes more Calcium Bicarbonate to produce a given alkalinity than it does of Calcium Carbonate, and it is found that for an equal weight of Calcium Bicarbonate the alkalinity value as compared against Calcium Carbonate is only 0.6174 parts. On the other side an equal weight of Calcium Hydrate will have an alkalinity value of 1.3506 parts; Sodium Hydroxide 1.2508—and so on.

From the foregoing it is seen that the compounds in these tables may be compared in two different ways against the Calcium Carbonate Standard for alkalinity, or against any other compound in the table. For instance, under the heading Sodium Hydroxide (NaOH) it is noted that one part is equal in alkalinity value to 1.3247 parts of Sodium Carbonate (Soda Ash); and, further, that one part of Sodium Carbonate is only equal to 0.9442 parts of Calcium Carbonate in raising alkalinity values.

ALKALINITY EQUIVALENTS*

Compound	Formula	$Al_2(OH)_6$	BaO	$Ba(OH)_2$	CaO	$Ca(OH)_2$	$CaCO_3$	$CaH_2(CO_3)_2$	MgO	$Mg(OH)_2$
Aluminum Hydrate	$Al_2(OH)_6$	*1.0000*	0.3390	0.3034	0.9271	0.7017	0.5195	0.3207	1.2895	0.8913
Barium Oxide	BaO	2.9494	*1.0000*	0.8948	2.7734	2.0697	1.5323	0.9461	3.8035	2.6289
Barium Hydrate	$Ba(OH)_2$	3.2959	1.1174	*1.0000*	3.0559	2.3128	1.7123	1.0572	4.2503	2.9377
Calcium Oxide	CaO	1.0785	0.3656	0.3272	*1.0000*	0.7568	0.5603	0.3459	1.3908	0.9613
Calcium Hydrate	$Ca(OH)_2$	1.4250	0.4831	0.4323	1.3212	*1.0000*	0.7403	0.4571	1.8376	1.2701
Calcium Carbonate	$CaCO_3$	1.9247	0.6525	0.5839	1.7845	1.3506	*1.0000*	0.6174	2.4821	1.7155
Calcium BiCarbonate	$CaH_2(CO_3)_2$	3.1174	1.0569	0.9458	2.8904	2.1876	1.6196	*1.0000*	4.0202	2.7786
Magnesium Oxide	MgO	0.7754	0.2629	0.2352	0.7189	0.5441	0.4028	0.2487	*1.0000*	0.6911
Magnesium Hydrate	$Mg(OH)_2$	1.1219	0.3803	0.3403	1.0402	0.7873	0.5828	0.3598	1.4468	*1.0000*
Magnesium Carbonate	$MgCO_3$	1.6216	0.5498	0.4920	1.5035	1.1379	0.8425	0.5201	2.0912	1.4454
Magnesium BiCarbonate	$MgH_2(CO_3)_2$	2.8143	0.9541	0.8538	2.6094	1.9749	1.4621	0.9027	3.6293	2.5085
Sodium Oxide	Na_2O	1.1922	0.4042	0.3617	1.1054	0.8366	0.6194	0.3824	1.5375	1.0627
Sodium Hydrate	NaOH	1.5387	0.5217	0.4668	1.4267	1.0798	0.7994	0.4935	1.9843	1.3715
Sodium Carbonate	Na_2CO_3	2.0385	0.6911	0.6184	1.8900	1.4305	1.0590	0.6538	2.6288	1.8169
Sodium Carbonate, Hydrated	$NaCO_3,10H_2O$	5.5033	1.8658	1.6697	5.1025	3.8619	2.8592	1.7653	7.0969	4.9052
Sodium BiCarbonate	$NaHCO_3$	3.2312	1.0955	0.9803	2.9958	2.2674	1.6787	1.0364	4.1669	2.8800
*Tri-Sodium Phosphate	Na_3PO_4	2.1028	0.7129	0.6380	1.9497	1.4756	1.0925	0.6745	2.7118	1.8743
Tri-Sodium Phosphate, Hydrated	$Na_3PO_4,12H_2O$	4.8747	1.6527	1.4790	4.5197	3.4207	2.5326	1.5636	6.2863	4.3449

Compound	Formula	$MgCO_3$	$(CO_3)_2$	Na_2O	NaOH	Na_2CO_3	Na_2CO_3, $10H_2O$	$NaHCO_3$	Na_3PO_4	Na_3PO_4, $12H_2O$
Aluminum Hydrate	$Al_2(OH)_6$	0.6166	0.3553	0.8387	0.6498	0.4905	0.1817	0.3094	0.4755	0.2151
Barium Oxide	BaO	1.8187	1.0480	2.4737	1.9167	1.4468	0.5359	0.9128	1.4025	0.6050
Barium Hydrate	$Ba(OH)_2$	2.0324	1.1711	2.7643	2.1419	1.6168	0.5989	1.0200	1.5672	0.6761
Calcium Oxide	CaO	0.6650	0.3832	0.9046	0.7009	0.5290	0.1959	0.3337	0.5128	0.2212
Calcium Hydrate	$Ca(OH)_2$	0.8787	0.5063	1.1952	0.9260	0.6990	0.2589	0.4410	0.6776	0.2923
Calcium Carbonate	$CaCO_3$	1.1869	0.6839	1.6143	1.2508	0.9442	0.3497	0.5956	0.9152	0.3948
Calcium BiCarbonate	$CaH_2(CO_3)_2$	1.9223	1.1076	2.6146	2.0259	1.5292	0.5664	0.9647	1.4824	0.6395
Magnesium Oxide	MgO	0.4781	0.2755	0.6503	0.5039	0.3803	0.1409	0.2399	0.3687	0.1590
Magnesium Hydrate	$Mg(OH)_2$	0.6918	0.3986	0.9409	0.7291	0.5503	0.2038	0.3472	0.5334	0.2301
Magnesium Carbonate	$MgCO_3$	*1.0000*	0.5762	1.3601	1.0538	0.7955	0.2946	0.5018	0.7711	0.3326
Magnesium BiCarbonate	$MgH_2(CO_3)_2$	1.7354	*1.0000*	2.3604	1.8289	1.3806	0.5113	0.8709	1.3382	0.5773
Sodium Oxide	Na_2O	0.7352	0.4236	*1.0000*	0.7748	0.5848	0.2166	0.3689	0.5669	0.2445
Sodium Hydrate	NaOH	0.9488	0.5467	1.2906	*1.0000*	0.7548	0.2796	0.4762	0.7317	0.3156
Sodium Carbonate	Na_2CO_3	1.2570	0.7243	1.7097	1.3247	*1.0000*	0.3704	0.6308	0.9693	0.4181
Sodium Carbonate, Hydrated	$NaCO_3,10H_2O$	3.3936	1.9554	4.6157	3.5764	2.6996	*1.0000*	1.7031	2.6169	1.1289
Sodium BiCarbonate	$NaHCO_3$	1.9925	1.1481	2.7100	2.0998	1.3850	0.5871	*1.0000*	1.5364	0.6628
Tri-Sodium Phosphate	Na_3PO_4	1.2967	0.7471	1.7637	1.3665	1.0315	0.3821	0.6504	*1.0000*	0.4313
Tri-Sodium Phosphate, Hydrated	$Na_3PO_4,12H_2O$	3.0059	1.7320	4.0885	3.1679	2.3913	0.8857	1.5078	2.3181	*1.0000*

* Prepared by the late C. Arthur Brown, of Lorain, Ohio.

Limits for Toxic Wastes in Sewage Treatment*

by STUART E. COBURN

Late Chief Chemist, Metcalf and Eddy, Cons. Engrs., Boston, Mass.

AN examination of the recent literature reveals a large number of articles describing the objectionable effects of various industrial wastes on sewage treatment. The factual evidence from these reports shows that these wastes have caused various troubles, from "excessive foaming" or "retarded digestion of sludge" to a complete breakdown of treatment plant facilities.

It is apparent that the deleterious effects of any industrial waste vary inversely with the dilution afforded by the sewage. Thus, the wastes from a certain industry in a small community might disrupt the treatment plant, whereas its effect in the sewage of a large city would be inconsequential.

Effects of Toxic Wastes

The objectionable effects of an industrial waste may be due to one or more of its various constituents. As an illustration, in the manufacture of mouton fur the following substances may cause trouble in treatment:

1. Grease and excess alkali from the scouring of the skins clog the sewers and retard biological treatment.
2. Heavy suspended solids both from the washing and the tanning overload primary treatment.
3. Toxic chromium from the mineral tan prevents digestion of sludge.
4. Large quantities of organic material having an excessively high oxygen demand overload oxidation processes.

Other wastes have their own characteristic effects. Tanneries, breweries, canneries, slaughter houses, textiles, rubber, metallurgical wastes, and numerous others, have different effects on sewage treatment.

Chromium salts, usually reported in the form of metallic chromium, have different effects on different units of a sewage treatment plant. The chromium is in the trivalent form in spent chrome alum in the wastes discharged from a tannery using a mineral tan. Chromium in this form will precipitate almost quantitatively in an alkaline solution such as sewage, and will be removed as sludge to digestion tanks, where digestion will be retarded or practically stopped. If secondary treatment is used there will probably be very little trouble biologically. On the other hand, if the chromium compounds are discharged from a plating establishment or from anodyzing of aluminum, the chromium is chiefly in the hexavalent form. Chromium cannot be precipitated under ordinary conditions in this form. Therefore, the effect on sludge digestion is very much less. However, in the hexavalent form the chromium is much more toxic, and when present in sufficient quantities will kill the organisms in filters or in activated sludge. The tolerance concentration is controversial. It has been reported to the writer that quantities up to 25 p.p.m. can be handled continuously. Edwards found that shock loads of about 40 p.p.m. slowed up nitrification and caused deterioration in the appearance of activated sludge effluent. Information is still lacking as to the quantity of chromium which is permissible in sewage under the following variable conditions:

1. Type of chromium, trivalent or hexavalent.
2. Type of sewage treatment, such as primary and secondary.
3. Continuous flow versus shock loads over a period of a few hours.

Copper is a toxic substance easier to evaluate. As reported by Mohlman an excess of 1 p.p.m. has caused trouble.

Acid-iron wastes have caused trouble at Worcester, Fostoria, and in many other places.

Daily, weekly or monthly analyses have usually been reported. The question arises as to whether or not the trouble was caused by intermittent discharges of pickling liquors high in iron or acid content, or by a continuous discharge of wastes containing much smaller quantities of iron and acid. Zinc has been reported as detrimental to sludge digestion at Fostoria, Ohio.

Cyanides of 5 p.p.m. discharged continuously have an inhibiting effect on activated sludge treatment. Doses of 20 p.p.m. are reported as having an immediate effect on activated sludge, but after removal of the cyanide, the sludge recovers. Siebert reports that as low as 1 p.p.m. is toxic to biological activities. On the other hand, filtration of much higher concentrations of cyanide, through sand or coke breeze, has been suggested as a method of treatment.

From another point of view cyanides should not be permitted in sewage because of the slight possibility of acid wastes being present at the same time and therefore possible liberation of hydrocyanic acid.

Brewery wastes have interfered with sewage treatment at Jeanette, Pennsylvania. It was found during a recent investigation that the B.O.D. population-equivalent of the waste from a single brewery was greater than the population of the entire city.

Rubber wastes at Akron so overloaded the primary treatment units that the sewage plant reached its designed capacity long before the estimated time.

Substances such as acids, alkalies, silt, plastics, and grease, which cause localized troubles in a sewer, may also cause serious results at the sewage treatment plant.

Soluble cutting oils, while affecting treatment to some degree, are objectionable in that they pass through tanks unchanged and cause marked objectionable effect on the appearance of the receiving stream.

Control of Toxic Wastes

The writer takes the view that industrial wastes should be admitted to municipal sewer systems to the extent that they do not cause breakdown of the collection or treatment facilities either physically or biologically, or so overload the various units that the effluent is impaired to an objectionable degree. In other words, the presence of industrial wastes may cause temporary overloading and accompanying operational vexations, but pollution abatement is nearer being solved and the public better served by treatment of all wastes possible with the sewage in one plant, under the supervision of competent operators.

Whenever the proportion of wastes becomes so great that the sewage treatment plant becomes a wastes treatment plant, it is necessary for industry either to remove its wastes or to pretreat them to an acceptable degree. New sewage treatment plants may be designed to handle the industrial wastes of the municipality if their character and quantity can be predicted.

It is difficult but necessary that certain limitations be placed on the quantity of objectionable or toxic substances that may be present in sewage as received at the treatment plant. Such limits have been proposed by the Allegheny County Sanitary Authority. Table I has been taken from the Authority's recent report "Proposed Collection and Treatment of Municipal Sewage and Industrial Wastes."

It is the writer's opinion that if these concentration limits are met there will be no difficulty in treatment by the usual sewage treatment processes. In fact, it is probable that these limits can be exceeded manifold for short periods without any harmful effect.

A committee is needed to establish maximum limits of objectionable constituents of industrial wastes that are proposed to be treated with municipal sewage.

TABLE I

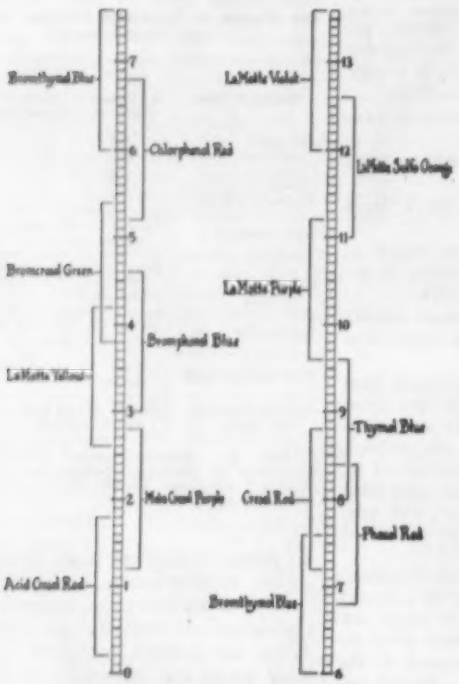
Concentration Limits for Toxic and Deleterious Wastes in Composite Sewage of Treatment Plant Influent*

Names of Items	Primary Treatment		Secondary Treatment
	No Sludge Digestion	Sludge Digestion	
pH index	5.0	6.5	6.5
Total iron (p.p.m.)	5.0	5.0	5.0
Copper (p.p.m.)	3.0	3.0	1.0
Chromium (p.p.m.)	5.0	5.0	3.0
Cyanide (p.p.m.)	2.0	2.0	2.0
Oils—mineral	Should be excluded by municipal ordinances.		
Oils—soluble	Removed to maximum practicable extent before discharge.		
Combustibles, etc.	Should be excluded by municipal ordinances.		
Free mineral acids	Should be neutralized at source.		
Acetylene generation sludge	Should be excluded by municipal ordinances.		

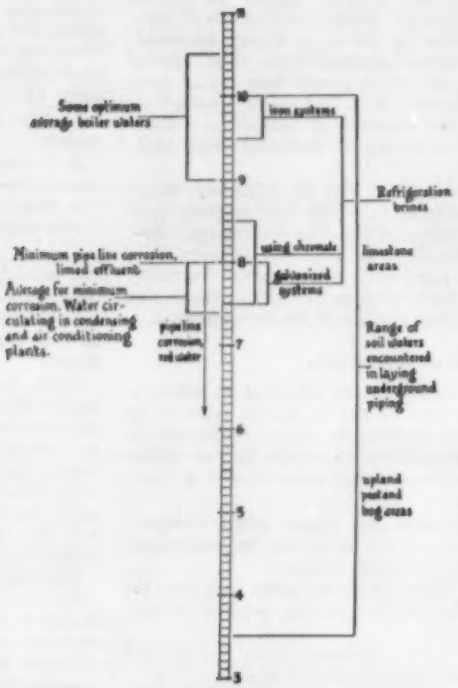
*Page 22, "Report—Proposed Collection and Treatment of Municipal Sewage and Industrial Wastes," Allegheny County Sanitary Authority (January, 1948).

*Reprinted from Sew. Wks. Jour., Vol. 21, p. 522 by permission.

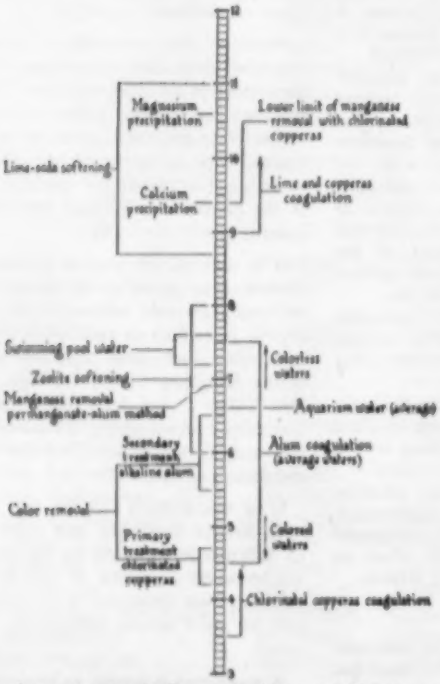
pH Zones in Water and Sewage Treatment*



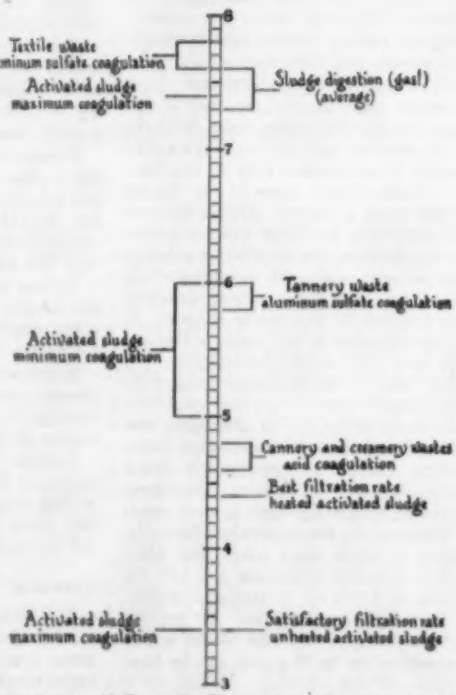
Ranges of Selected Indicators for PH Determination



Approximate pH Zones Encountered in Common Corrosion Problems



Approximate pH Zones for Water Purification



Approximate pH Zones for Treatment of Sewages and Some Industrial Wastes

*Reproduced from the reference work "pH and Its Practical Application"—LaMotte, Kenny & Reed—(Williams and Wilkins, Publishers, Baltimore, Md.)

Use of Inhibitors in Cleaning Metallic Pipe

by ALLEN ABRAMS* and C. L. WAGNER*
Rothschild, Wis.

WATER pipes in certain sections of the country are likely to become clogged by corrosion or deposits from the water. In many cases this has reqired replacement of the pipes, a procedure which is often costly due to the necessity of tearing out walls and floors. As a result there have been attempts to clean pipes by the use of muriatic or other acids with the intent to leave the acid in just long enough to remove the scale and yet not long enough to attack the pipe itself. This, however, is a questionable expedient and may be more expensive than the replacement of the pipes.

During the last decade considerable interest has been shown in the use of inhibitors in pipe cleaning operations involving acid treatment. These are usually nitrogenous materials such as aniline or pyridine; and, even glue and flour have been used. When small quantities of such substances are added to an acid solution the resultant mixture will attack rust or scale but will have practically no effect on the pure metal itself. Wide use has therefore been made of this principle in the acid process of "pickling" metals to effectively remove scale while rendering the loss of metal underneath almost negligible.

An example is also given of the use of this principle in cleaning the pipes of a thirty-five story office building located in downtown New York.**

Many of the pipes were concealed behind expensive marble walls and it was estimated that it would cost between $100,000 and $300,000 to replace this piping, not to mention the serious inconvenience to tenants. By the use of an acid-inhibitor combination the whole cleaning operation was carried out on Saturday afternoon without inconvenience to the tenants. The pipes were returned to practically their normal condition of carrying capacities and the cost of the operation was but nominal.

This method attracted our attention in 1927 and we made initial tests to determine how effectively inhibitors would reduce the action of acid on the metal. In parallel tests on galvanized iron pipes 16 per cent muriatic acid was used alone, to compare with the same acid containing 3 per cent of an inhibitor. Equal lengths of pipe were allowed to stand in each solution for six hours. At the end of that time the pipe in muriatic acid had lost 50 per cent of its weight while that in the inhibited acid had lost but 0.2 per cent of its weight. We were then satisfied that the inhibitors would effectively prevent destruction of the pipes by such acid when submerged for a relatively short period.

Working Demonstrations

Not long afterwards two lengths of pipe, leading from the basement of our main office to the second floor became filled with rust and other deposit, completely stopping the passage of steam. It would have been relatively expensive to replace this piping and we therefore opened the two lengths at the top and cleaned them by pouring in inhibited acid, allowing it to work its way through. One overnight treatment, followed by a thorough flushing was sufficient to clean these pipes and no further trouble was encountered.

Early this year the Marathon County Board decided that it would be necessary to tear out and replace all the water piping in the Mount View Sanatorium due to the fact that it was so stopped up that it was impossible to get an adequate water supply through the system. When the matter was brought to our attention we suggested that an attempt be made to clean several lengths of this pipe and a decision could then be made as to the further course to be pursued.

Twenty-five gallons of 14 per cent muriatic acid were treated with 3 per cent, by volume, of the inhibitor.*** The treated acid was placed in a barrel to which was connected the suction of a small rotary pump. The acid was then forced upward from the basement to the second floor through a length of one-inch pipe, thence through a cross-over and down through another length of pipe to the basement. The returning acid passed through a fine screen to remove any dislodged particles and thence to the solution barrel.

At the beginning of the test a considerable amount of solid material was dislodged from the pipes and it was almost impossible to force the acid through. The pipes were then opened on the second floor, the acid mixture was poured in and allowed to flow by gravity until the pipes were filled. The bottom openings were plugged, the acid allowed to stand for eight hours and the acid withdrawn and the pipes thoroughly flushed. Examination indicated that the scale had been practically completely removed.

Control Procedure

In order to determine how effectively the cleaning was being done, three 6-inch lengths were cut from a 1-inch pipe, which was so clogged with rust and dirt that it was barely possible to get a pencil into the opening. One of these pipes was retained without treatment and the other two were connected in the circuit through which the acid was being pumped. At the end of about two hours one length of pipe was removed and found to be almost completely clean except for small patches of rust on the walls. After ten hours the other length of pipe removed for examination proved to be entirely free of rust and scale and there was no apparent action on the metal itself.

In the cleaning operation approximately 2,800 feet of pipe were treated, ranging from ⅜ inch to 4 inches in diameter. Estimates by George Baumgardt, who was in charge of the plumbing work, showed that the total labor costs were $870, while the cost of acid and inhibitor was approximately $20—a total of $890. Mr. Baumgardt estimated that the cost of replacing the piping would have been:

Galvanized pipe fittings and valves	$1,000
Labor for installation	5,000
Plaster, concrete floor and repainting	2,500
Total	$8,500

*Department of Research and Development, Marathon Paper Mills Co., for which the senior author is Technical Director. Mr. Wagner is chemist.

**"Removing Rust from a System with Piping Acid," F. N. Speller, E. L. Chappell and R. P. Russell—Chem. and Met. Engineering, July, 1927.

***Inhibitors are available, from several of the larger chemical companies—Barrett & Co., Monsanto Chemical Co., General Chemical Co., et al.

Effect of Altitude on Pumps

When a pump is operated at elevations above sea level, the lower atmospheric pressures encountered have a double effect on the pump performance.

1. The lower atmospheric pressure cannot support as high a column of water so that the maximum practical suction lift decreases.

2. The lower atmospheric pressure reduces the horsepower output of the gas engine, thus causing it to lose speed which results in a loss of capacity and discharge head of the pump.

At elevations above sea level, the suction lift on the pump should be reduced accordingly to insure that the same amount of water can get into the pump as would get in at the equivalent sea level lift. The following table gives equivalent suction lifts for various elevations.

Altitudes	Suction Lifts in Feet			
Sea level	10	15	20	25
2,000 ft.	8.8	13.2	17.6	22
4,000 ft.	7.8	11.7	15.6	19.5
6,000 ft.	6.9	10.4	13.8	17.3
8,000 ft.	6.2	9.3	12.4	15.5
10,000 ft.	5.7	8.6	11.4	14.3

When a gas engine driven pump is operated at elevations of 4,000 ft. or over, the engine should be equipped with a high altitude head. However, even with a special cylinder head, there is still a power loss of approximately 3 per cent for every 1,000 ft. of elevation. This will result in a loss of speed, and a loss of pump performance. The following table gives the loss in performance that can be expected at various elevations.

Altitude	Percentage of Sea Level Discharge	Percentage of Sea Level Head
	Percent	
Sea level	100	100
2,000 ft.	97	95
4,000 ft.	95	91
6,000 ft.	93	87
8,000 ft.	91	83
10,000 ft.	88	78

A Useful "All Purpose" Pipe Chart

By W. F. SCHAPHORST, M.E.

Newark, N. J.

ENGINEERS and operators often want to know certain things about pipe, and they want to know quickly; perhaps the cubic feet of liquid or gas flowing through the pipe per minute, the gallons per minute, the pounds of water per minute, the velocity of flow, or the exact internal diameter of the pipe regardless of its standard.

All of these quantities are more or less dependent upon each other, the important question usually being the true size of the pipe. Since pipe sizes vary as they do, standard pipe not being exact in internal diameter and extra heavy pipe being different also, it is frequently necessary to search through tables and make more or less lengthy calculations before arriving at the result. And then, after a result is arrived at, one is not always certain that the answer is correct.

Note Three Lines in Column A

Here is a chart that takes care of most of these matters in a decidedly simple way. The best way to explain the method of application of the chart is to give a problem. First, it will be observed that there are three sets of figures given in connection with the extreme left hand column, which is designated as column A. The first column of figures at the left marked "1 standard" gives the actual internal diameter of standard pipe. This column shows, for example, that the internal diameter of a 1-in. standard pipe is somewhat greater than 1 in. because the column of figures marked "2 Exact" gives the exact diameter. Thus, if we have a pipe the internal diameter of which is exactly 2 in., as used in the problem which is cited below, we use this column of figures. The next column of figures, marked "3 Extra Heavy," gives the actual internal diameter of a 1-in. extra heavy pipe as less than 1 in.

Solving a Problem

Now let us apply the chart to a problem, as follows: How much water is passing through a pipe having an internal diameter of exactly 2 in., the velocity of the water being 2 ft. per sec.?

Locate the 2 in column A over the word "exact" and from its point of intersection run a straight line through the 2 ft. per sec. in column C as shown by the slanted dotted line. This straight line intersects column B. From the point of intersection in column B run a straight line over to the identical point in column G, also as shown by the dotted line. The intersection of this perfectly horizontal line from column B to column G gives answers simultaneously in the three columns D, E, and G. It shows that according to column D, 2.6 cu. ft. per min. as flowing through the pipe. Column E shows that the volume of flow amounts to 19.5 gal. per min. And column F tells us that if it is water, the weight of that water is about 165 lb. per min.

It is evident now, on studying the chart, that if the pipe were a 2-in. standard pipe instead of being exactly 2 in., the horizontal line from column B to column G would be slightly lower and the three quantities in columns D, E, and F would be slightly greater. On the other hand, it is evident that if a 2-in. extra heavy pipe were used instead of a 2-in. exact, the horizontal line from column B to G would be raised slightly above its shown position and the three quantities in columns D, E, and F would therefore be slightly less.

Working the Scales Backwards

Inversely, if any quantity in columns D, E, and F is known and it is desired to determine the velocity per second of flow through the pipe, this same chart can be used with equal ease. First run the horizontal line through the known point in D, E, or F, and then through the located point in column B run a straight line from the known pipe diameter and the intersection with column C immediately gives the velocity of the liquid in feet per second.

Or if you wish to select a pipe size, knowing any one of the quantities in D, E, or F, and having decided upon the velocity of flow, it is perfectly evident what to do.

Use as a Conversion Chart

At the same time it will be observed that this chart can be conveniently employed as a conversion chart. For example, how many gallons in 2.6 cu. ft.? The dotted horizontal line already drawn shows that the answer is about 19.5 gal., which is also equivalent to about 165 lb. of water. At the same time this chart gives a visual demonstration of the relationship between pipe sizes—standard, exact, and extra heavy. By using this chart one can quickly "read off" the internal diameter of a standard or extra heavy pipe.

The range of this chart is great enough to take care of almost any problem one may encounter. The standard pipe sizes range from ⅛ in. to 15 in., and the velocities from 0.3 to 30 ft. per second.

In the event that the liquid is other than water, multiply the weight of water by the density or specific gravity of the liquid and you then have the weight of the desired liquid. Thus, for example, if it is an oil having a specific gravity of 0.9 we would have in the above problem $165 \times 0.9 = 148.8$ pounds of oil.

Formulas

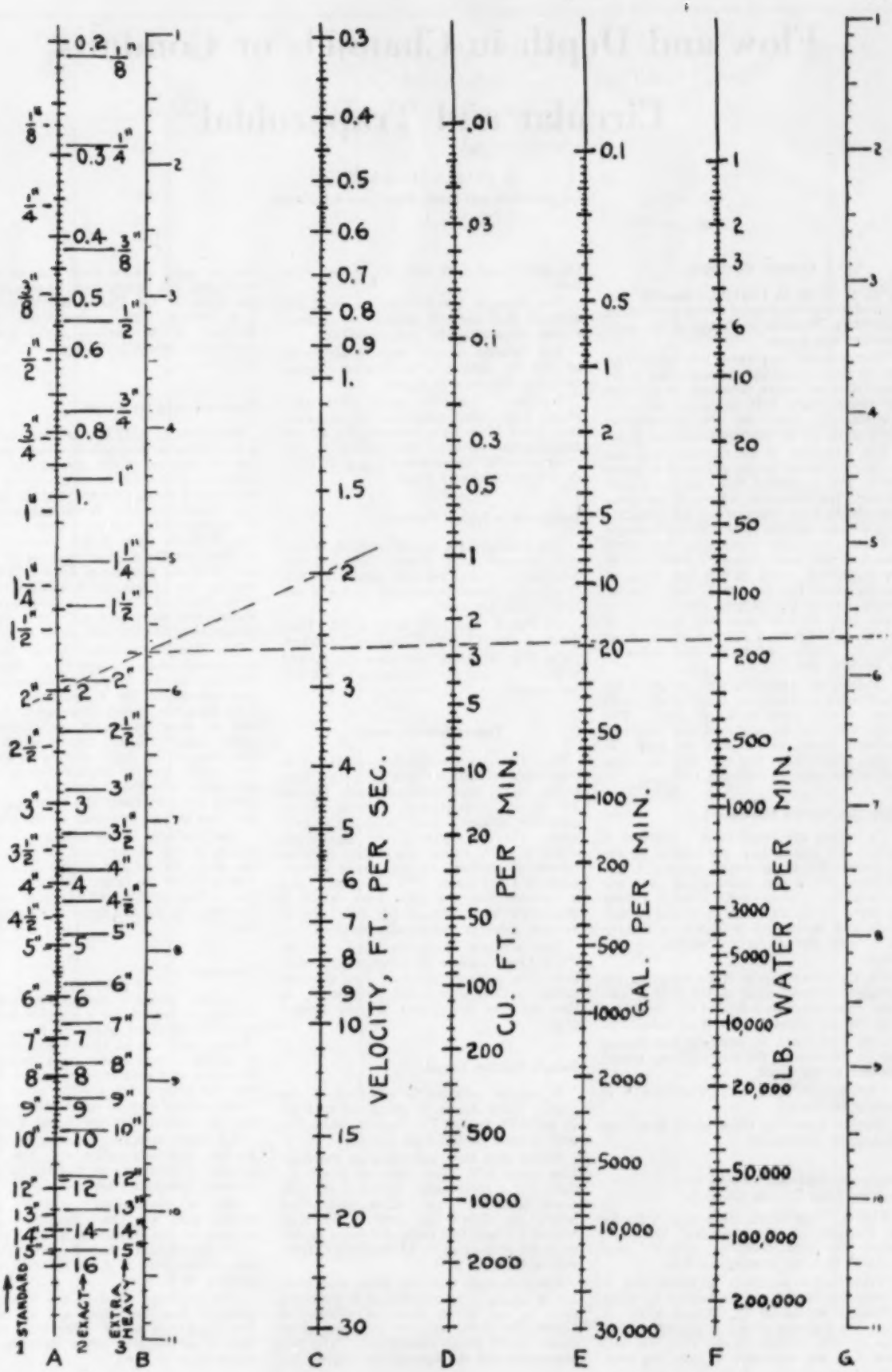
And finally, should one prefer to use formulas rather than this chart, either for solving the problem directly or for checking the results taken from the chart, here are the formulas on which the chart is based:

$$Q = 2.45\ d^2\ V$$

where Q = gallons per minute;
d = internal diameter of pipe, inches;
V = velocity of liquid, feet per second.

Cu. ft. per min. $= 0.327\ d^2\ V$

Lb. water per min. $= 20.4\ d^2\ V$


VELOCITY, FT. PER SEC.
CU. FT. PER MIN.
GAL. PER MIN.
LB. WATER PER MIN.
1 STANDARD
2 EXACT
3 EXTRA HEAVY
A
B
C
D
E
F
G

Flow and Depth in Channels or Conduits, Circular and Trapezoidal

by PAUL McH. ALBERT
Drury, McNamee, and Porter, Engrs., Ann Arbor, Mich.

Circular Conduits

FIG 1, "Flow in Circular Channels," introduces an extremely useful solution of Manning's Formula in terms of Q, n, s, diameter and *depth*.

The designer may enter this chart with any of these variables and study the problem. It is no longer necessary to compute the full capacity first, as is currently the practice, and later use the proportional chart or tables to compute fractional flows.

The simplicity of the nomograph is due to the calculation by the writer of a factor which will be called the Circular Depth Factor. The equation shown on the chart was obtained by substituting the elements of a circular section in Manning's Formula and mathematically eliminating the terms area and hydraulic radius. Calculation of the numerical value of the last term of the equation (in brackets), the Circular Depth Factor for definite ratios of h/D from 0.10 to 1.00 produced a table of values which were graduated on the scale (4), the position of each being indicated by its h/D ratio.

Students of hydraulics will recognize the significance of the upper range of this h/D scale, which folds back on itself. The value 0.90 has no practical use and was included purely to complete the scale. It shows graphically that the flow is practically the same at 0.80 and 1.00.

Some Uses for the Nomograph

To extend the range of n, a scale of n values was placed near the bottom of the Q scale, 0.013 being placed opposite 1 cfs. It takes only a few moments to copy one cycle of the Q scale on the edge of a sheet of paper. This may then be placed on any cycle and moved up or down in accordance with the directions shown on the chart.

As the exceptionally large range of the variables includes most of the field of circular channels, only a few of the important uses for the nomograph will be noted.

The free-board in semi-circular flumes can be determined for any capacity within the size of the flume.

Prefiling of hydraulic gradients is greatly facilitated.

Storage capacities above given flows can be quickly determined.

Discharge, Area and Velocity in Partially Filled Circular Conduits

Fig. 2, "Discharge, Area and Velocity in Partially Filled Circular Sections", solves the two formulas, $Q=AV$ and $A=xD^2$, A being common to both.

Velocity for problems in which Fig. 1 is used can be quickly determined by using the same values of Q, D and h/D. A scale for Velocity Head is placed on one side of the velocity scale (5). In this case it is not necessary to note the area, but merely use that line (3) as the pivot line.

The formula $Q=AV$ can be used for sections that are not circular in shape—square or trapezoidal for instance.

The formula $A=xD^2$ may be also used to find the volume of horizontal circular cylinders for various depths.

Separately, the two charts offer completely independent equations, but, together, they solve Manning's Formula for all the fundamental variables encountered in circular sections. These are (Q, n, s, D, h/D, A, V) and Velocity Head.

Solution of a Typical Problem

The solution of a typical problem is carried through both charts. To find the depth of flow and velocity when $n=0.013$, $Q=30$ cfs, $D=60$ inches and $s=1.6$ ft. per 1,000 (0.16 per cent).

On Fig. 1, find h/D to be 0.372. Then depth of flow $(L)=0.372\times60=22.3$ inches.

On Fig. 2, using the same Q, D and $h/D=0.372$, find the velocity to be 4.5 feet per second.

Trapezoidal Channels

Fig. 3 is for solving flow problems in trapezoidal channels. In Fig. 3, two very useful charts have been combined. On the left is the nomographic solution of the equation obtained from Manning's Formula. On the right is the logarithmic chart of d/b ratios for eight different shapes of channel, varying from vertical sides to a 4:1 slope. The two charts have a common line, the *Base Line*, which is graduated for values of the d/b ratio of vertical sides or rectangular sections.

Two straight lines intersecting at the *Pivot Line* complete the nomographic solution. The point on the *Base Line* thus obtained is then transferred horizontally to that scale of d/b ratios for the desired slope.

Sample Problem Solved

A sample solution is indicated on the chart. Here 36 cfs. is connected with 0.1 ft. per 1000 ft. and 7 ft. bottom width (b) with a point on the Base Line.

Notice that the graduation on the Base Line reads 0.76. The depth of flow (d), then, for a rectangular section 7 ft. wide would be 0.76×7.0 or 5.32 ft. deep. Now follow the dotted line over to the scale headed 1:1 and find there the value of d/b to be 0.5 or d equal to 3.5 ft. for a channel with side slopes of 1:1.

The d/b ratio for any other side slope can be as easily determined, or if the depth ratio in one given shape of channel is known, the depth ratio for any other given shape can be found immediately. The *bottom width* and the *flow* do not change unless the point on the Base Line is moved vertically. All values must be moved back and forth to the Base Line *horizontally*. The curved lines connect the major divisions of the various scales and are used solely to assist the eye in finding the divisions.

Construction of the Graph

Inasmuch as 0.025 is a common value of n used with earth channels, it was used for the construction of the nomograph. Other values of n may be used by shifting the Q scale up or down until the desired value of n is opposite 1.0 cfs. A convenient method of accomplishing this is to copy a cycle or two of the Q scale, in the ranges of your problem, on the edge of a sheet of paper and mark the position of 1.0 cfs. Then by placing the 1.0 cfs. mark against the desired value of n, the Q scale has been shifted and the copied scale will give the values of Q for the new value of n.

The sample equation solved on the nomograph was obtained from Manning's Formula in the following manner. Q/A was substituted for V and then A/p for r (p being the wetted perimeter). Then A and p were expressed in dimensional terms, namely: b, the bottom width; d/b, the ratio of the depth of flow to the bottom width; and the angle ϕ formed by the side slope and the horizontal. By transposing and combining like terms the equation was formed as shown on the chart.

The last term in the equation, in parentheses, is the factor used in constructing the scales for the side slopes. The numerical values of the factor were used to locate the position of the graduations of the ratio d/b but only the d/b ratios are given in the chart.

Comments

All the primary dimensional variables which are needed for a solution are contained in the chart. Any one, two, or more of them may not be known and often only Q is known and others must be assumed to arrive at a satisfactory answer. It matters but little which are the given values. Other values may be immediately assumed and the answer obtained in but a moment.

All other variables, as velocity, area of section, hydraulic radius, etc., can be calculated, if necessary or desired, for all the physical dimensions are known.

Most of the ordinary problems can be solved with the chart inasmuch as the ranges of the variables include a 1 ft. wide rectangular channel flowing but a few inches deep to a 20 ft. wide channel flowing 40 ft. deep.

The problems involved are those where uniform flow conditions will be satisfied. For conditions where other than uniform flow is encountered, other methods of analysis must be used.

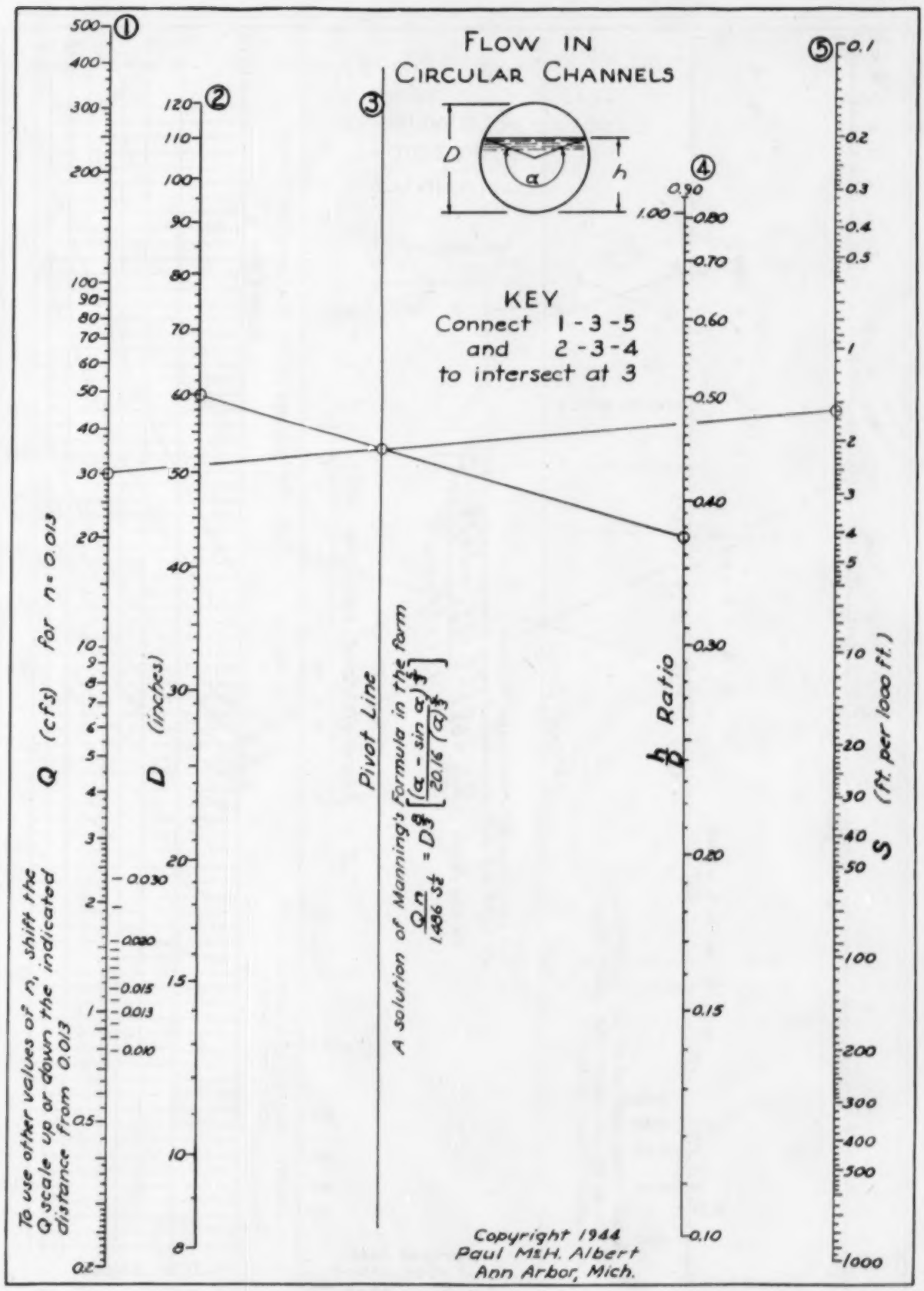
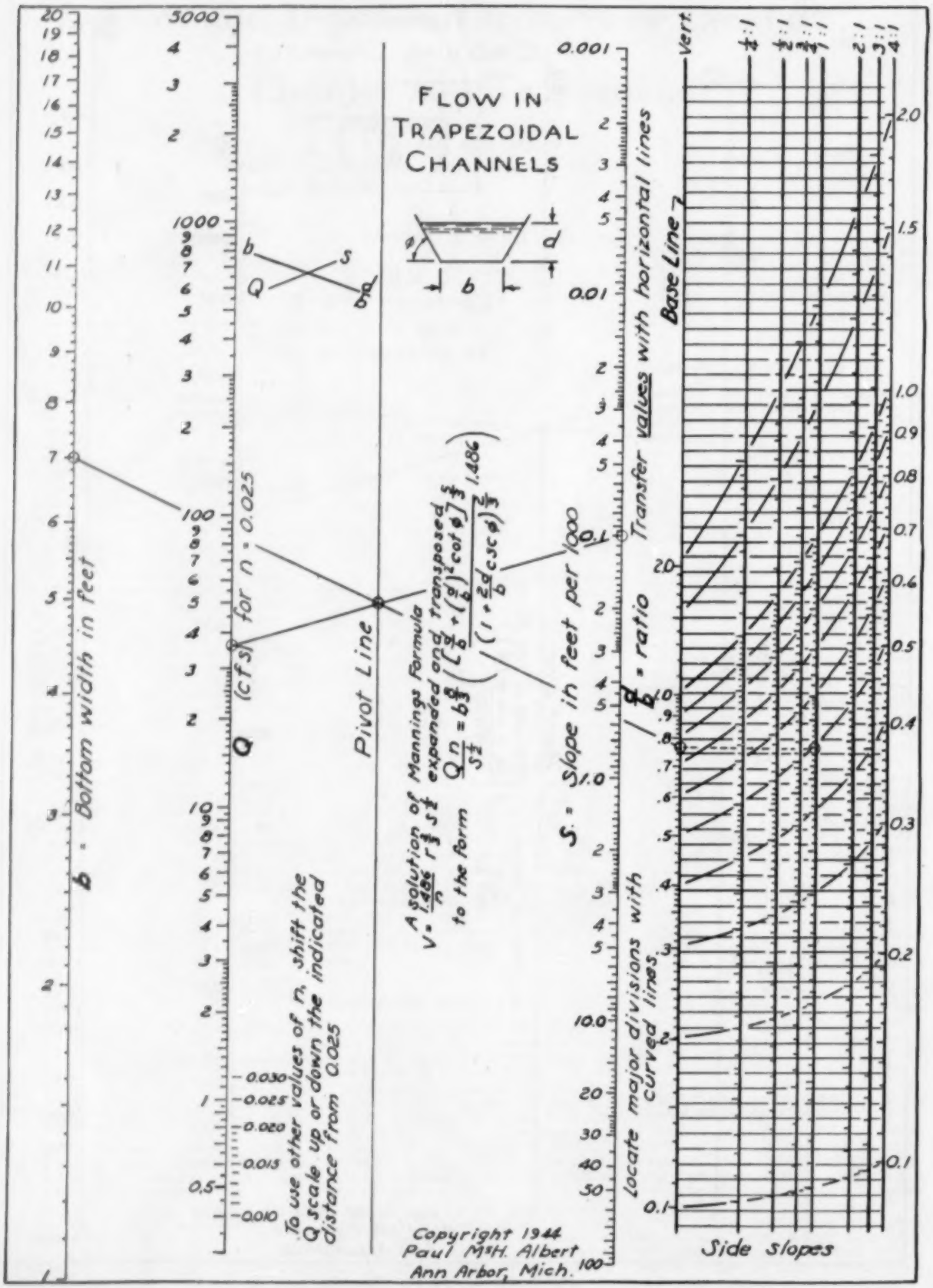
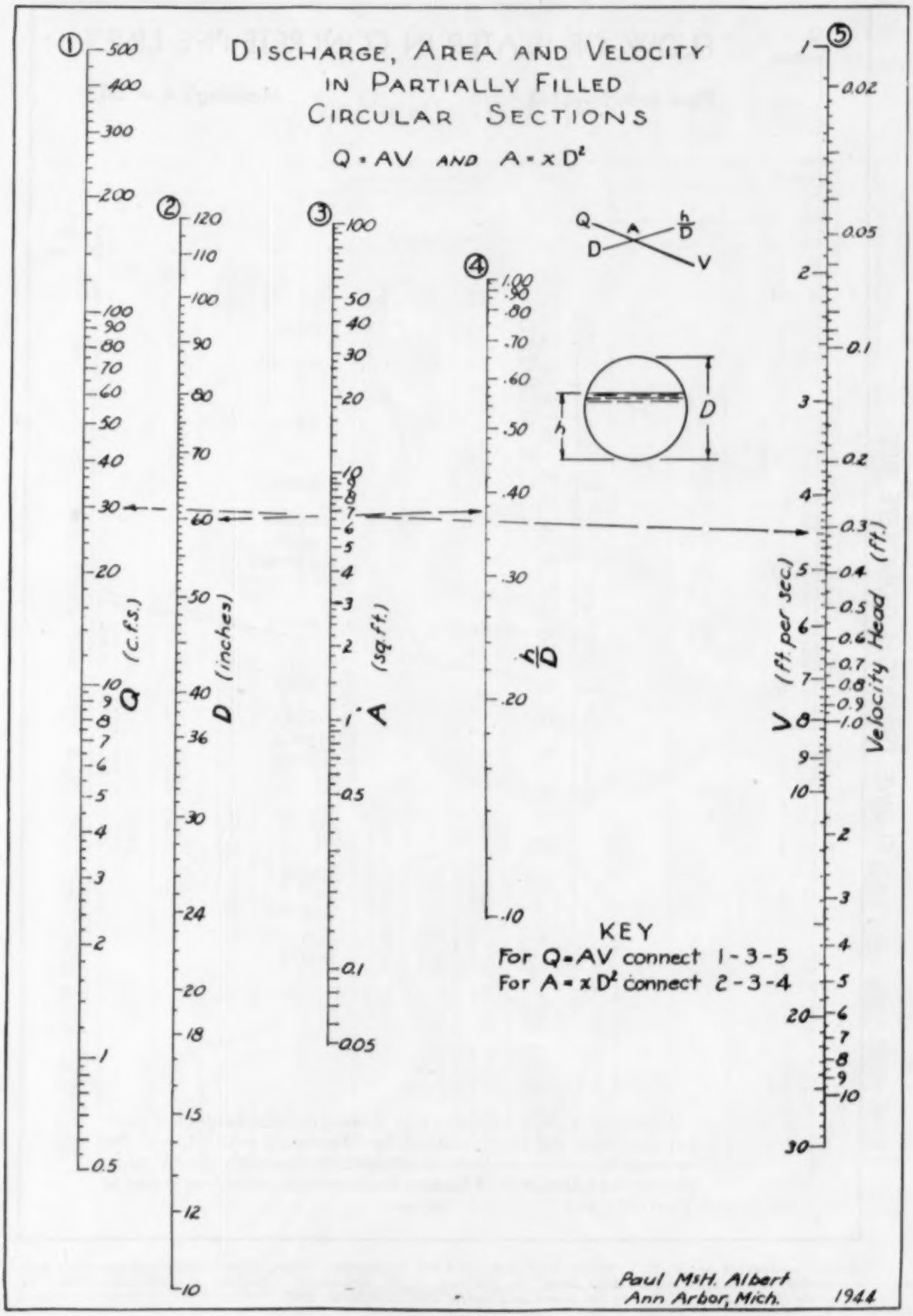


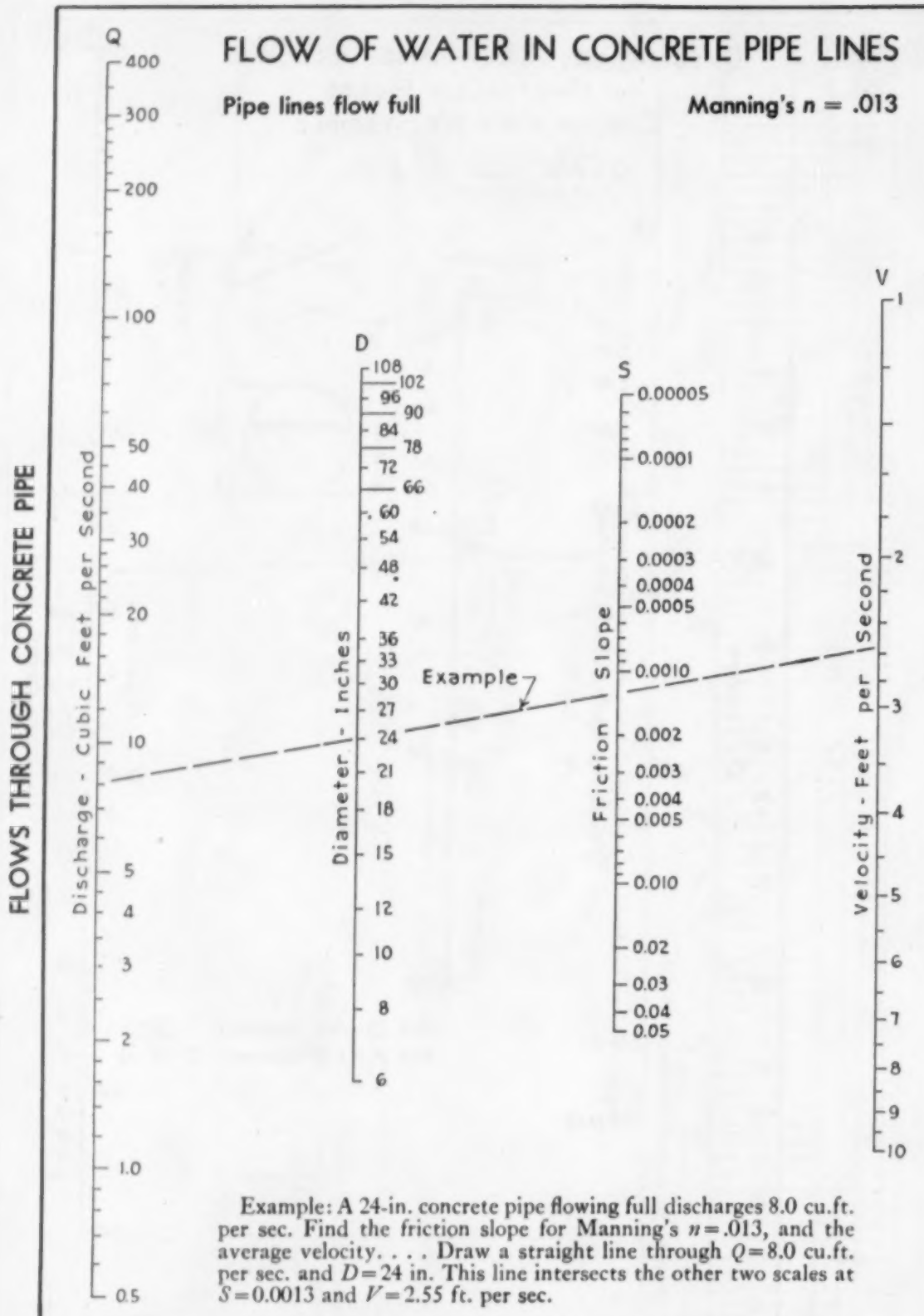
Fig. 1.—Flow in Circular Channels


FLOW IN TRAPEZOIDAL CHANNELS
b = Bottom width in feet
Q (cfs) for n = 0.025
Pivot Line
S = Slope in feet per 1000
d/b = ratio
Transfer values with horizontal lines
Base Line
Vert.
Side Slopes
To use other values of n, shift the Q scale up or down the indicated distance from 0.025
Locate major divisions with curved lines.
A solution of Mannings Formula V = 1.486/n r^⅔ s^½ expanded and transposed to the form Qn/s^½ = b^⅜ (d/b + (d/b)^4 cot^4 φ)^⅝ / ((1 + 2d/b csc φ)^⅔)^1.486
Copyright 1944 Paul M.H. Albert Ann Arbor, Mich.


DISCHARGE, AREA AND VELOCITY
IN PARTIALLY FILLED
CIRCULAR SECTIONS
Q = AV AND A = x D²
① Q (c.f.s.)
② D (inches)
③ A (sq. ft.)
④ h/D
⑤ V (ft per sec.) Velocity Head (ft.)
Q A h/D D V
KEY
For Q = AV connect 1-3-5
For A = x D² connect 2-3-4
Paul McH. Albert
Ann Arbor, Mich.
1944

FLOW OF WATER IN CONCRETE PIPE LINES

Pipe lines flow full — **Manning's n = .013**



FLOWS THROUGH CONCRETE PIPE

Example: A 24-in. concrete pipe flowing full discharges 8.0 cu.ft. per sec. Find the friction slope for Manning's n=.013, and the average velocity. . . . Draw a straight line through Q=8.0 cu.ft. per sec. and D=24 in. This line intersects the other two scales at S=0.0013 and V=2.55 ft. per sec.

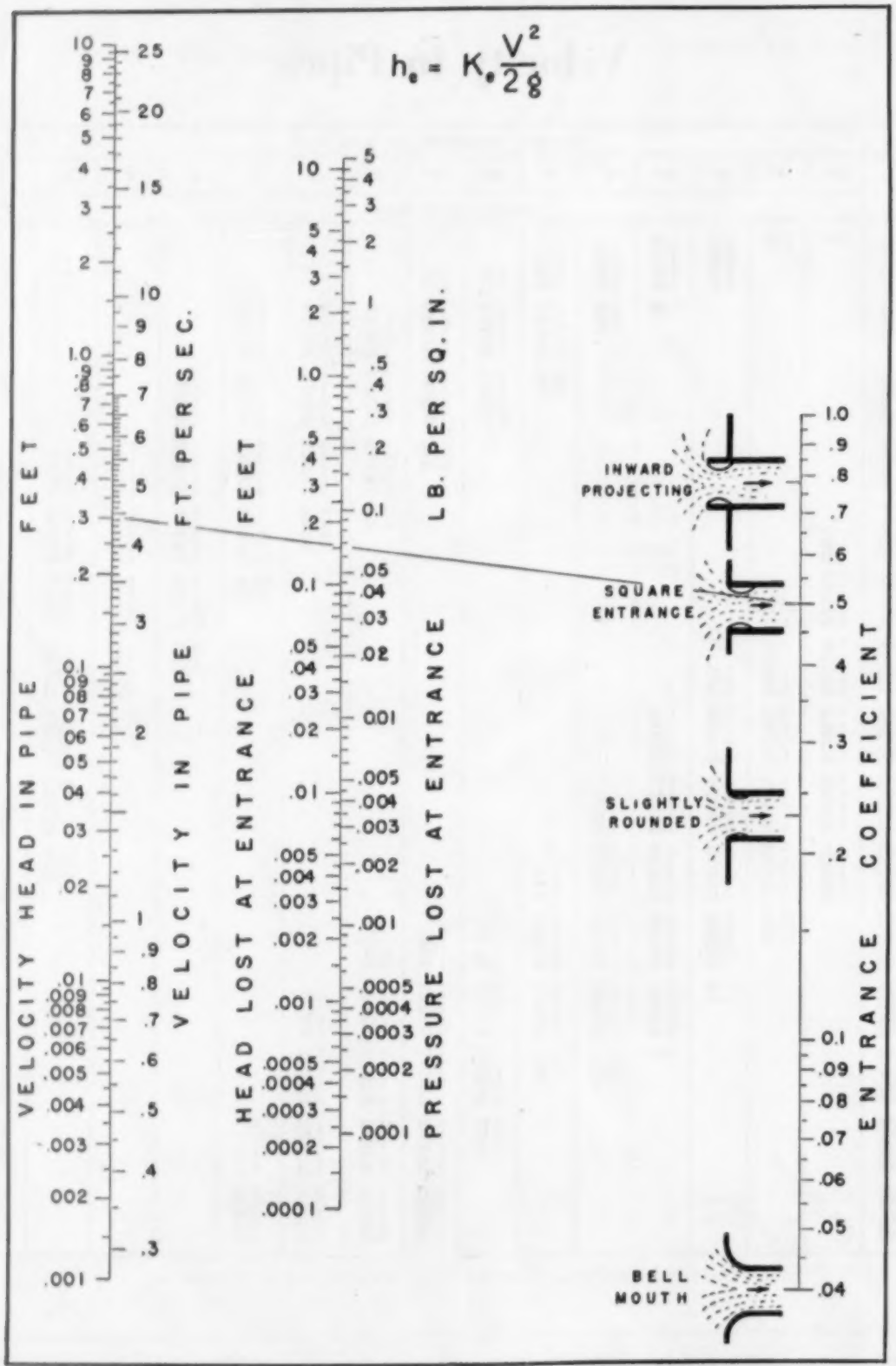
A chart constructed by Dr. F. T. Mavis, head Dept. of Civil Engineering, Penna. State College and appearing with the chapter "Flow of Water In Pipe Lines" by Professor J. E. Christiansen, University of California, written for "Concrete Pipe Lines," published by the American Concrete Pipe Association, 1942.

Velocity In Pipes

Rate of Flow in Gals. per Min.	NOMINAL DIAMETER OF PIPE (Velocity in Feet Per Second)														Rate of Flow in Gals. per Min.
	⅜"	½"	¾"	1"	1¼"	1½"	2"	2½"	3"	4"	5"	6"			
1	5.60	3.08	1.67	1.05											1
2		6.16	3.35	2.10	1.20										2
3			5.02	3.16	1.80	1.12									3
4			6.70	4.21	2.41	1.49	0.86	0.63							4
5			8.37	5.26	3.01	1.86	1.07	0.79							5
10				10.52	6.02	3.72	2.14	1.57	1.02	0.65	0.45				10
15					9.02	5.60	3.21	2.36	1.53	0.98	0.68				15
20					12.03	7.44	4.29	3.15	2.04	1.31	0.91				20
25						9.30	5.36	3.94	2.55	1.63	1.13				25
30						11.15	6.43	4.72	3.06	1.96	1.36				30
35						13.02	7.51	5.51	3.57	2.29	1.58				35
40						14.88	8.58	6.30	4.08	2.61	1.82				40
45							9.65	7.08	4.60	2.94	2.04	1.02			45
50							10.72	7.87	5.11	3.27	2.27	1.28			50
70							15.01	11.02	7.15	4.58	3.18	1.79	1.14		70
75								11.80	7.66	4.90	3.40	1.92	1.22		75
100								15.74	10.21	6.54	4.54	2.55	1.63	1.10	100
120								18.89	12.25	7.84	5.45	3.06	1.96	1.36	120
125									12.75	8.16	5.66	3.19	2.04	1.42	125
150									15.32	9.80	6.80	3.84	2.45	1.70	150
175									17.85	11.40	7.94	4.46	2.86	1.98	175
200	8"								20.42	13.07	9.08	5.11	3.27	2.27	200
225										14.70	10.20	5.75	3.67	2.55	225
250	1.60									16.30	11.32	6.38	4.08	2.84	250
270	1.73										12.25	6.90	4.41	3.06	270
275	1.76										12.50	7.03	4.49	3.12	275
300	1.92										13.62	7.66	4.90	3.40	300
350	2.24	10"										8.94	5.72	3.98	350
400	2.56											10.21	6.54	4.54	400
450	2.88	1.84										11.49	7.35	5.11	450
470	3.01	1.92	12"									12.00	7.68	5.34	470
475	3.04	1.94										12.10	7.75	5.40	475
500	3.20	2.04	1.42									12.77	8.17	5.68	500
550	3.52	2.25	1.56										8.99	6.24	550
600	3.84	2.45	1.70	14"									9.80	6.81	600
650	4.16	2.65	1.85	1.30									10.62	7.38	650
700	4.48	2.86	1.99	1.40									11.44	7.94	700
750	4.80	3.06	2.13	1.50									12.26	8.50	750
800	5.12	3.27	2.27	1.60										9.08	800
850	5.45	3.47	2.41	1.70	15"									9.65	850
900	5.76	3.67	2.56	1.80	1.67									10.20	900
950	6.08	3.88	2.70	1.90	1.76									10.77	950
1000	6.40	4.08	2.84	2.00	1.85									11.34	1000
1050	6.72	4.29	2.98	2.10	1.95									11.90	1050
1100	7.04	4.49	3.13	2.20		16"								12.48	1100
1150	7.36	4.70	3.27	2.30	2.02									13.05	1150
1200	7.68	4.90	3.41	2.40	2.11	1.99								13.61	1200
1250	8.00	5.41	3.55	2.50	2.20	2.09								14.20	1250
1500	9.60	6.12	4.26	3.05	2.64	3.09									1500
2000	12.80	8.10	5.68	4.00	3.52		20"	24"	30"						2000
2500		10.20	7.10	5.01	4.40	3.98	3.07								2500
3000		12.24	8.52	6.01	5.28	4.78	3.53	2.43	1.81						3000
3500		14.50	9.95	7.02	6.16	5.58	4.10	2.83	1.90						3500
4000			11.36	8.02	7.04	6.33	4.30	2.97							4000
4200			11.92	8.42	7.40	6.70									4200
4500			12.78	9.02	7.92	7.17	4.61	3.19	2.04	36"					4500
5000			14.20	10.02	8.80	7.96	5.12	3.54	2.26						5000
5500				11.01	9.69	8.77	5.63	3.90	2.49						5500
6000				12.00	10.56	9.56	6.14	4.25	2.72	1.57					6000
6500				13.00	11.44	10.36	6.66	4.60	2.94	2.05					6500
7000				14.02	12.32	11.16	7.16	4.97	3.17	2.21					7000
7200					13.20	11.50	7.38	5.16	3.26	2.27					7200
7500					14.00	11.96	7.68	5.32	3.40	2.37					7500
8000							8.20	5.66	3.62	2.52					8000
8500							8.70	6.02	3.85	2.68					8500
9000							9.21	6.38	4.08	2.84	42"				9000
9200							9.72	6.72	4.31	3.00					9200
10000							10.24	7.08	4.58	3.15	2.31				10000
10500								7.44	4.76	3.30	2.43				10500
11000								7.79	4.99	3.46	2.55				11000
11500								8.15	5.22	3.62	2.66				11500
12000								8.50	5.44	3.78	2.78				12000
12500								8.85	5.67	3.93	2.89				12500
13000								9.20	5.90	4.08	3.01				13000
13500								9.54	6.12	4.25	3.13				13500

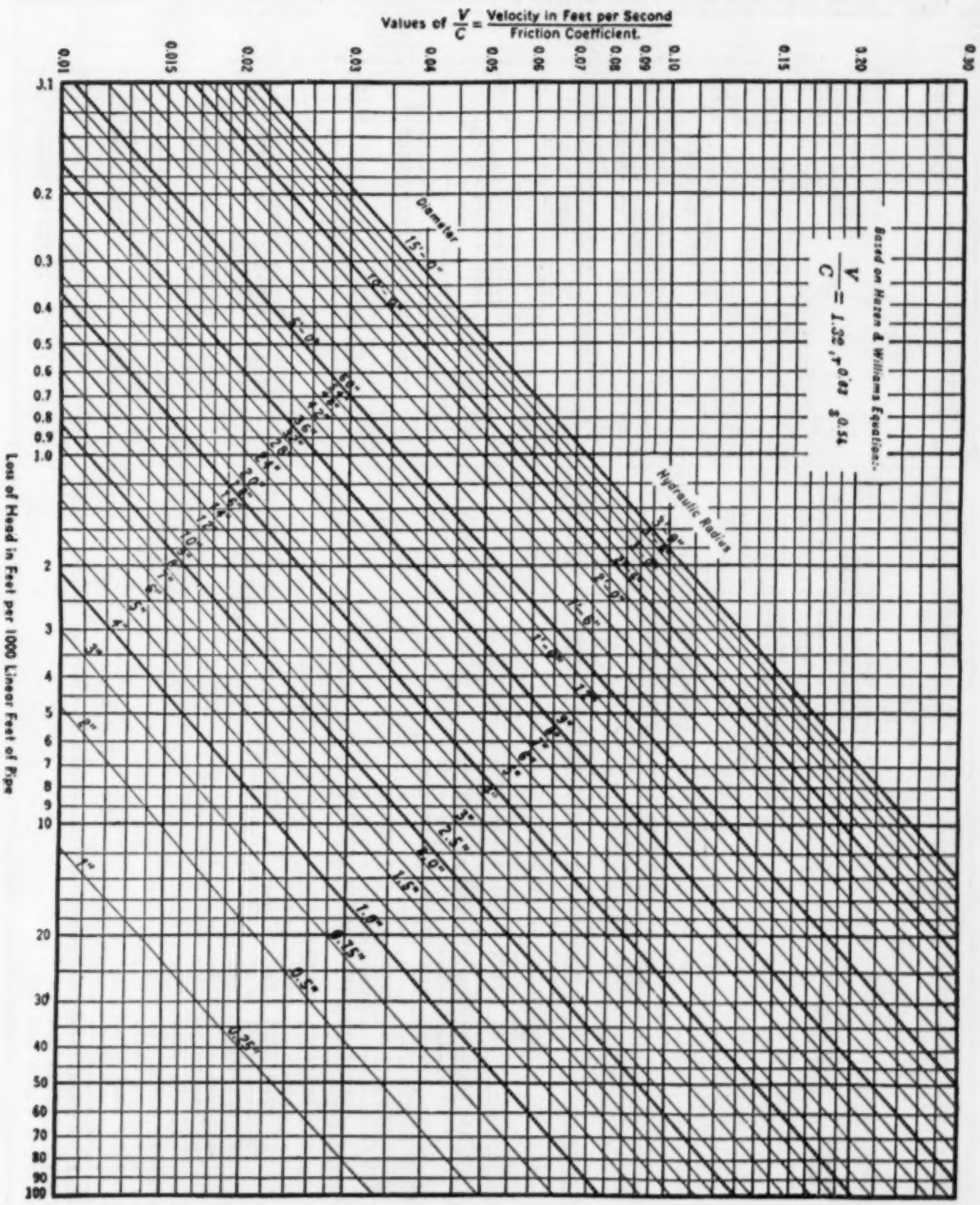
This table is taken from "Hydraulic Data," published by Gould's Pumps, Inc.

Hydraulic Entrance Losses



Courtesy of J. R. Griffith, U. S. Navy, and Western Construction News.

Chart of Loss of Head in Feet Per 1000 Ft. of Pipe



From "Hydro-Electric Handbook"—John Wiley & Sons

Friction of Water Pipes

The pipe frictions shown in the following tables are taken by permission from the more complete copyright tables by Williams and Hazen, published by John Wiley & Sons, and these values are recommended for use in figuring pipe frictions.

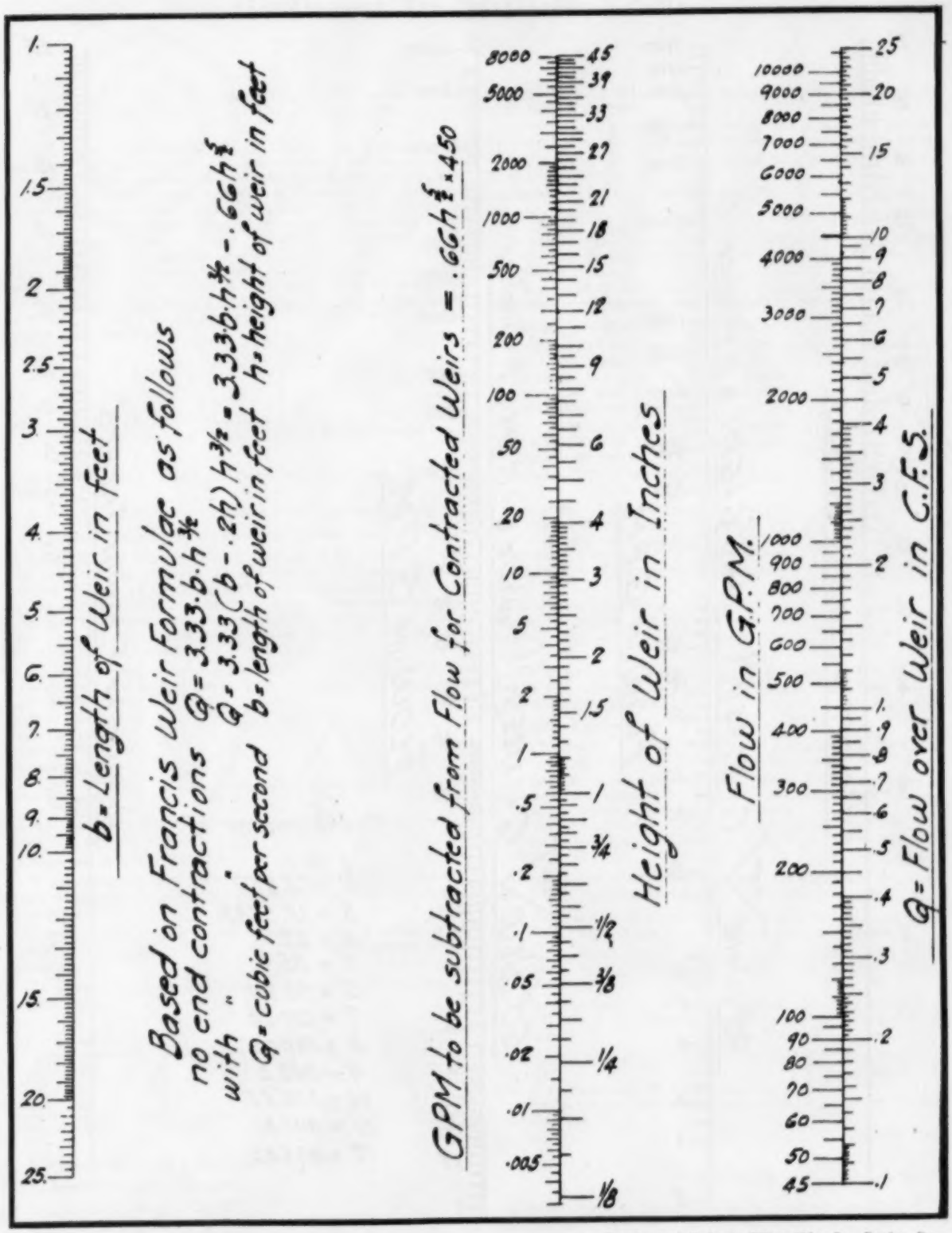
Loss of Head in Feet Due to Friction, per 100 feet of 15 year old Ordinary Iron Pipe

U.S. Gal's per Min.	1" Pipe		1¼" Pipe		1½" Pipe		2" Pipe		2½" Pipe		3" Pipe	
	Vel.	Fric.	Vel.	Fric.	Vel.	Fric.	Vel.	Fric.	Vel.	Fric.	Vel.	Fric.
10	3.72	11.7	2.14	3.05	1.57	1.43	1.02	0.50	0.65	0.17	0.45	0.07
15	5.60	25.0	3.2	6.50	2.36	3.0	1.53	1.0	0.98	0.36	0.68	0.15
20	7.44	42.0	4.29	11.1	3.15	5.2	2.04	1.82	1.31	0.61	0.91	0.25
25	9.30	64.0	5.36	16.6	3.94	7.8	2.55	2.73	1.63	0.92	1.13	0.38
30	11.15	89.0	6.43	23.5	4.72	11.0	3.06	3.84	1.96	1.29	1.36	0.54
35	13.02	119.0	7.51	31.2	5.51	14.7	3.57	5.1	2.29	1.72	1.59	0.71
40	14.88	152.0	8.58	40.0	6.3	18.8	4.08	6.6	2.61	2.20	1.82	0.91
45			9.65	50	7.08	23.2	4.60	8.2	2.94	2.80	2.05	1.15
50			10.72	60	7.87	28.4	5.11	9.9	3.27	3.32	2.27	1.38
70			15.01	113	11.02	53.0	7.15	18.4	4.58	6.2	3.18	2.57
90					14.17	84.0	9.19	29.4	5.88	9.8	4.09	4.08
100					15.74	102.0	10.21	35.8	6.54	12.0	4.54	4.96
120					18.89	143.0	12.25	50.0	7.84	16.8	5.45	7.0
140					22.04	190.0	14.30	67.0	9.15	22.3	6.35	9.2
160							16.34	86.0	10.46	29.0	7.26	11.8
180							18.38	107.0	11.76	35.7	8.17	14.8
200							20.42	129.0	13.07	43.1	9.08	17.8
220							22.47	154.0	14.38	52.0	9.99	21.3
240							24.51	182.0	15.69	61.0	10.89	25.1
260							26.55	211.0	16.99	70.0	11.80	29.1
280									18.30	81.0	12.71	33.4
300									19.61	92.0	13.62	38.0

U.S. Gal's per Min.	4" Pipe		5" Pipe		6" Pipe		8" Pipe		10" Pipe		12" Pipe		14" Pipe		15" Pipe		16" Pipe		20" Pipe		24" Pipe	
	Vel.	Fric.	Vel.	Fric.	Vel.	Fric.	Vel.	Fric.	Vel.	Fric.	Vel.	Fric.	Vel.	Fric.	Vel.	Fric.	Vel.	Fric.	Vel.	Fric.	Vel.	Fric.
40	1.02	0.22																				
45	1.17	0.28																				
50	1.28	0.34																				
70	1.79	0.63	1.14	0.21																		
75	1.92	0.73	1.22	0.24																		
100	2.55	1.22	1.63	0.41	1.14	0.14																
120	3.06	1.71	1.96	0.58	1.42	0.25																
125	3.19	1.86	2.04	0.64	1.48	0.28																
150	3.84	2.55	2.45	0.88	1.71	0.32																
175	4.45	3.44	2.86	1.18	2.00	0.48																
200	5.11	4.40	3.27	1.48	2.28	0.62																
225	5.77	5.45	3.67	1.86	2.57	0.74																
250	6.40	6.72	4.08	2.24	2.80	0.92	1.60	0.22														
270	6.90	7.70	4.42	2.60	3.03	1.13	1.70	0.25														
275	7.03	7.99	4.50	2.72	3.06	1.15	1.73	0.27														
300	7.66	9.30	4.90	3.14	3.40	1.29	1.90	0.32														
350	8.90	12.32	5.72	4.19	3.98	1.75	2.20	0.42														
400	10.21	16.00	6.54	5.40	4.54	2.21	2.60	0.54														
450	11.50	19.80	7.35	6.70	5.12	2.65	2.92	0.68	1.80	0.21												
470	12.10	22.40	7.70	7.22	5.49	2.90	3.07	0.75	1.92	0.24												
475	12.20	22.96	7.76	7.42	5.55	2.95	3.10	0.76	1.94	0.25												
500	12.77	24.00	8.17	8.12	5.60	3.30	3.20	0.82	2.04	0.28	1.42	0.11										
550			8.99	9.60	6.16	3.93	3.52	0.97	2.25	0.33	1.57	0.14										
600			9.80	11.30	6.72	4.70	3.84	1.14	2.46	0.39	1.71	0.15										
650			10.62	13.20	7.28	5.40	4.16	1.34	2.66	0.46	1.85	0.19	1.37	0.09								
700			11.44	15.10	7.84	6.20	4.46	1.54	2.86	0.52	2.00	0.22	1.47	0.10								
750			12.26	17.20	8.50	7.00	4.80	1.74	3.06	0.59	2.13	0.24	1.58	0.11								
800					9.08	8.00	5.12	1.97	3.28	0.67	2.27	0.27	1.68	0.13								
850					9.58	8.95	5.48	2.28	3.48	0.75	2.41	0.31	1.79	0.14								
900					10.30	10.11	5.75	2.46	3.68	0.83	2.56	0.34	1.89	0.16								
950					10.72	10.80	6.06	2.87	3.88	0.91	2.70	0.38	2.00	0.18	1.73	0.12						
1000					11.32	12.04	6.40	3.02	4.08	1.01	2.84	0.41	2.10	0.19	1.82	0.14						
1050					11.90	13.30	6.70	3.21	4.29	1.09	2.98	0.44	2.20	0.22	1.91	0.16						
1100					12.50	14.31	7.03	3.51	4.50	1.20	3.13	0.49	2.31	0.23	2.00	0.17						
1150					12.95	15.60	7.35	3.84	4.71	1.34	3.27	0.53	2.42	0.25	2.09	0.18						
1200					13.52	16.69	7.67	4.15	4.91	1.46	3.41	0.57	2.52	0.26	2.18	0.19						
1250					14.10	18.50	8.00	4.45	5.11	1.51	3.55	0.62	2.63	0.29	2.28	0.20	1.99	0.15				
1500							9.60	6.27	6.10	2.09	4.20	0.85	3.15	0.39	2.73	0.28	2.39	0.21				
2000							12.70	10.71	8.10	3.65	5.60	1.43	4.20	0.66	3.64	0.54	3.19	0.39			1.42	0.05
2500									10.10	5.33	7.00	2.28	5.25	1.01	4.55	0.72	3.99	0.56			1.77	0.07
3000									13.10	7.80	8.40	3.15	6.30	1.47	5.46	1.12	4.79	0.80	3.08	0.27	2.13	0.10
3500									14.10	10.08	9.80	4.10	7.35	1.81	6.37	1.43	5.59	1.04	3.59	0.35	2.49	0.14
4000											11.35	5.32	8.40	2.47	7.28	1.85	6.38	1.34	4.10	0.45	2.85	0.18
4200											11.93	6.00	8.82	2.80	7.64	2.08	6.72	1.45	4.32	0.50		
4500											12.78	6.90	9.45	3.22	8.19	2.23	7.20	1.65	4.62	0.56	3.20	0.22
5000											14.20	8.40	10.50	3.92	9.10	2.78	7.96	2.02	5.13	0.68	3.54	0.27
5500													11.55	4.65	10.01	3.30	8.78	2.39	5.64	0.82	3.90	0.33
6000													12.60	5.50	10.92	3.90	9.56	2.60	6.15	0.96	4.25	0.38
6500													13.65	6.45	11.83	4.55	10.36	3.32	6.66	1.06	4.61	0.45
7000													14.70	7.15	12.74	5.08	11.12	3.68	7.18	1.28	4.97	0.52
7200															13.10	5.45	11.50	3.96	7.38	1.35		
7500															13.65	5.90	11.95	4.28	7.66	1.45	5.32	0.59
8000																			8.17	1.63	5.68	0.66
8500																			8.68	1.83	6.03	0.74
9000																			9.20	2.04	6.35	0.81
9500																			9.70	2.23	6.74	0.91
10000																			10.40	2.53	7.07	0.98

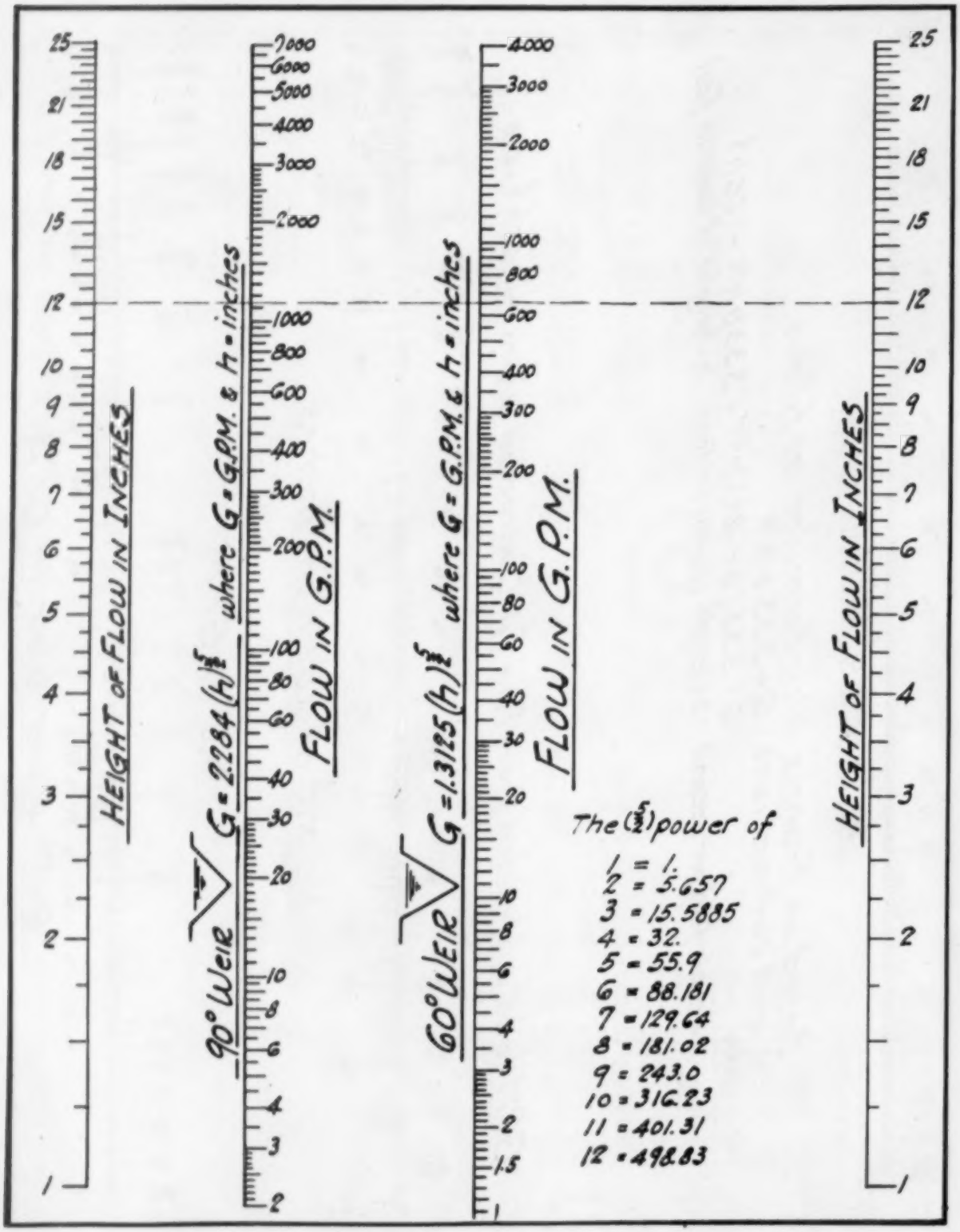
Vel.—Velocity ft. per second. Fric.—Friction head in feet.

Chart for Capacity of Rectangular Weirs


b = Length of Weir in feet
Based on Francis Weir Formulae as follows
no end contractions Q = 3.33.b.h^3/2
with " Q = 3.33(b - .2h).h^3/2 = 3.33.b.h^3/2 - .66h^5/2
Q = cubic feet per second b = length of weir in feet h = height of weir in feet
GPM to be subtracted from Flow for Contracted Weirs = .66h^5/2 x 450
Height of Weir in Inches
Flow in G.P.M.
Q = Flow over Weir in C.F.S.

Courtesy of Roberts Filter Mfg. Co., Darby, Pa.

Chart for Capacity of 60° and 90° V-Notch Weirs


HEIGHT OF FLOW IN INCHES
90° WEIR
G = 2.2284 (h)^5/2 where G = G.P.M. & h = inches
FLOW IN G.P.M.
60° WEIR
G = 1.3125 (h)^5/2 where G = G.P.M. & h = inches
FLOW IN G.P.M.
HEIGHT OF FLOW IN INCHES
The (5/2) power of
1/2 = 1.
1 = 5.657
3 = 15.5885
4 = 32.
5 = 55.9
6 = 88.181
7 = 129.64
8 = 181.02
9 = 243.0
10 = 316.23
11 = 401.31
12 = 498.83

Courtesy of Roberts Filter Mfg. Co., Darby, Pa.

Calculation of Areas, Volumes, Surfaces Reduced to Simple Terms

Mensuration is arithmetic applied to geometry in determining the length of lines, the area of surfaces, and the volume of solids or bodies.

Definitions of geometrical terms, figures and principles. A point (.) has position only. A line (———) has length only. Area has length and breadth. A solid has length, breadth and thickness. Parallel means extended in the same direction, and equidistant at all points. Horizontal means parallel with water level; vertical or perpendicular, parallel with plumb line; diagonal, obliquely across a polygon. (Fig. 4.) Equilateral means, having equal sides. Quadrilateral, having four sides. An angle (Fig. 1) is formed by two straight lines diverging from a commont point called the vertex. A right angle (Fig. 2) is formed by two straight lines meeting perpendicularly. An oblique angle is either (acute—Fig. 1) smaller, or (obtuse—Fig. 3) greater than a right angle.

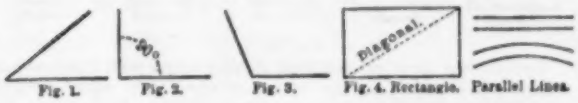


Fig. 1. Fig. 2. Fig. 3. Fig. 4. Rectangle. Parallel Lines.

A plane or plane figure has area or surface only—perfectly even.

A polygon is a plane figure having three or more equal sides.

A triangle is a plane figure bounded by three straight lines.

An equilateral triangle (Fig. 6) has all of its (3) sides equal. An isosceles triangle (Fig. 7) has two of its sides equal. A scalene triangle (Fig. 5) has none of its sides equal. The base is the side on which a geometrical figure is supposed to stand. The least distance between the base and the opposite angle dotted line (Fig. 7) or between parallel lines (Fig. 8) is called the perpendicular or altitude.

To find the area of a triangle. Rule—Multiply base by the altitude and take half of the product. Or, when the three sides are given. From half of the sum of the three sides, subtract each side separately; then multiply the half sum and the three remainders together and extract the square root. Find sq. ft. in a triangle, base 8 ft., altitude 9 ft.

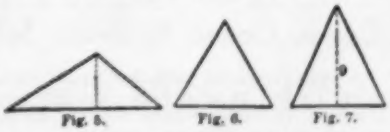


Fig. 5. Fig. 6. Fig. 7.

Answer—$(8 \times 9) \div 2 = 36$.

A parallelogram is a plane figure, bounded by four straight lines, whose opposite sides are equal, as a rectangle, a square, and a rhomboid.

A rectangle is a right angled parallelogram. A square is an equilateral rectangle. A rhomboid is an oblique angled parallelogram.

To find the area of a parallelogram. Rule—Multiply the length by the width.

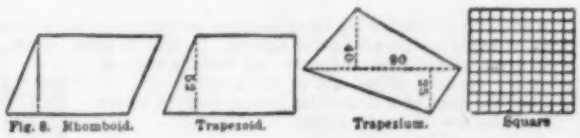


Fig. 8. Rhomboid. Trapezoid. Trapezium. Square

How many sq. ft. in a rectangle 17 by 24?

Answer—$17 \times 24 = 408$ sq. ft.

In a (square) floor 10 by 10?

Answer—$10 \times 10 = 100$ sq. ft.

Note—Dividing the area of a rectangle by one side gives the other side—if unknown.

A *trapezoid* is a quadrilateral having two of its sides parallel. To find its area. Rule—Multiply its average length by the width.

How many sq. yd. in a garden whose parallel sides are 60 and 80 yd., and width 52 yd.?

Answer—$(60 + 80 \div 2) = 70$; then, $70 \times 52 = 3{,}640$ sq. yd.

A *trapezoid* is a quadrilateral having two of its sides parallel.

To find its area. Rule—Form two triangles by a diagonal line, then multiply diagonal by sum of perpendiculars and take half of product.

Find sq. rods in field shaped like a trapezium, whose diagonal is 90 rods, and perpendiculars (25 and 40) 65 rd.

Answer—$90 \times 65 = 5850 \div 2 = 2925$ rd.

A *rightangled triangle* has one right angle. Its longest side is called hypotenuse, and the other two, base and perpendicular or altitude. To find its area. Rule—Multiply the base by the perpendicular and take half of the product.

How many square rods in a triangular field whose base is 70 rods and the perpendicular, 48 rods?

Answer — $(70 \times 48) \div 2 = 1680$ square rods.

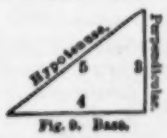


Fig. 9. Base.

Properties of the rightangled triangle. The square of the hypotenuse equals the sum of the squares of the base and the perpendicular. From this principle—illustrated by Fig. 10—we derive the following rules.

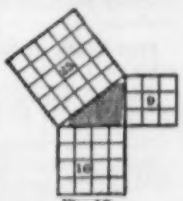


Fig. 10.

To find the hypotenuse. Rule—Add the square of the base and the square of the perpendicular, and of the sum extract square root.

A and B start from the same point, A going 4 miles due west and B, 3 miles due north; how far apart are they then?

$4^2 = 16$
$3^2 = 9$
$\sqrt{25} = 5$

Answer—5 miles.

The square of 4 (base)$=16$; of 3 (perpendicular)$=9$; the square root of their sum $(25)=5$, the hypotenuse.

To find the base or perpendicular. Rule—From the square of the hypotenuse, subtract the square of the other given side, and of their difference extract the square root.

Find the perpendicular of a triangular field whose hypotenuse is 75 rods, base 60 rods. Answer—45 rods.

$75^2 = 5625$
$60^2 = 3600$
$\sqrt{2025} = 45$

Note—To find the difference between the squares of two numbers, simply multiply their sum by their difference.

To find the side of a square equal in area to any given quantity. Rule—Extract the square root of the given quantity.

Thus, the dimensions of a square field containing 4000 square rods must be $(\sqrt{4000} = 63.246)$ 63¼ rods, nearly. Proof: $63\frac{1}{4}^2 = 4000 +$

To find the diagonal of a square. Rule—Multiply one side of the square by 10, diminish the product by 1% of itself and divide remainder by 7.

What is the diagonal of a field 35 rods square?

This is a simple way of finding the hypotenuse of a triangle whose base and perpendiculars are equal.

$35 \times 10 = 350$,
1% of $350 = 3.5$
$7)346.5$
Ans. (rd.) 49.5

The Circle

A circle is a plane figure bounded by a curved line, (1, 1, 1, 1) called circumference, every point of which is equally distant from

the center. The diameter is a straight line (2, 2) across a circle, through its center. The radius is a straight line (3) from the center to the circumference. An arc is any part of the circumference (5, 5). A chord, a straight line (4) joining ends of an arc. A tangent (6) touches circum. without cutting it. A segment is space (C) enclosed by arc and chord. A sector, space (B) enclosed by two radii and arc. A quadrant (A) is 90° or the fourth part of circle. A circle is divided into 360°; from X to Y is 45°; from X to Z, 90°. A sextant is one-sixth of a circle.

Elements of the Circle.

To find the *circumference* of a circle, the diameter being given. Rule—Multiply the diameter by 3 1/7; for greater accuracy, by 3.1416.

Find circumference of bicycle wheel; diam. 28 in.

Answer—28 × 3 1/7 = 88 in.

To find the *diameter* of a circle, the circumference being given. Rule—Divide the circumference by 3 1/7, or multiply it by .3183.

Circumference of a tree 144½ in., find diam.

Answer—144.5 × 3183 = 46 in.

To find the *area* of a circle. Rule—Multiply the square of the diameter by .7854; or the square of the radius by 3.1416; or the square of the circumference by .07958.

Find the area of a piston 20 in. in diam.

Answer—20^2 × .7854 = 314.16 sq. in.

Over how many sq. ft. can a cow graze, staked to a rope 50 ft. long? Here, 50 feet is the radius.

Answer—50^2 × 3.1416 = 7854 sq. ft.

To find the *radius* of a circle, the area being given. Rule—Multiply the area by .3183 and extract the square root of the product.

Find length of halter, tied to stake, that will enable horse to graze on 1 acre.

Answer—Square feet in acre, 43560 × .3183 = 13865; $\sqrt{13865}$ = 117¾ ft. long.

Note—The circumference of a circle is 3.1416 times greater than the diameter. The number 3.1416 (called Pi); its reciprocal, .3183; its 4th part .7854, its 6th part .5236, and others, should be committed to memory as they are indispensable factors in computing the areas and volumes of circular figures and bodies.

To find the *area of a sector* of a circle. Rule—Take such a part of the circle as the degrees in the given arc, are part of 360. Thus, a sector whose arc is 40°, contains 40/360 or 1/9 of the area of the circle.

To find the side of the greatest square that can be inscribed in a given circle. Rule—Multiply the diameter of the circle by .707; or the circumference by .225.

The diameter of a log is 24 inches; how large a sill can be cut from it?

24 × .707 = 17 in. square, nearly.

To inscribe the greatest equilateral triangle. Rule—Multiply the diameter of the circle by .886.

Side of greatest inscribed hexagon equals the radius of a circle.

To find the diameter of a circle that will inscribe a given square. Rule—Multiply the side of the desired square by 1.414.

What must be diam. of a log to cut a sill 12 in. sq.?

Answer—12 × 1.414 = 17 in.

The area of the greatest square inscribed in a given circle is exactly ½ of the area of the least square circumscribed about the same circle—or the square of its diameter.

To find the area between the two *concentric circles*. Rule—Take the difference between the area of each circle. A simpler way is to multiply the sum of the two diameters by their difference, and the product by .7854.

Find the area included between two concentric circles whose diameters are 30 and 50 inches. (80, sum; 20, dif.)

Answer—20 × 80 = 1600 × .7854 = 1256.64 sq. in.

To find the diameter of a circle whose area is equal to the area of a given square. Rule—Multiply one side of the given square by 1.1284.

To find the side of a square whose area is equal to the area of a given circle. Rule—Multiply the diameter of the given circle by .8862.

To find the diameter of three greatest equal circles that can be inscribed in a given circle. Rule—Multiply the diameter of the given circle by .464.

Find the diameters of the three greatest circles that can be inscribed in a circle 50 in. in diam.

Answer—50 × .464 = 23.2 in.

An *ellipse* is a plane figure bounded by an oval curved line and has a long and a short diameter or axis.

To find its circumference. Rule—Multiply the sum of the two diameters by 3.1416, and take half of the product.

Ellipse.

Find the circumference of an ellipse whose diameters are .41 and 29 ft.

(41 + 29) = 70 × 3.1416 ÷ 2 = 110 ft. nearly.

To find the *area of an ellipse*. Rule—Multiply the product of the two diameters by .7854.

How many square ft. are there in an elliptical platform whose diameters are 60 and 40 ft.?

60 × 40 = 2400 × .7854 = 1885 sq. ft. nearly.

Polygons

To find the area of polygons, having equal sides and equal angles. Rule—Multiply the square of one of the equal sides—of a triangle, by .433; of a pentagon, by 1.7205; of hexagon, by 2.5981; of octagon, by 4.8284.

One side of an equilateral triangle is 30 inches, and of an octagon, 10 in.

Find sq. in. in each.

30^2 × .433 = 389.7 in. T; 10^2 × 4.824 = 482.84 in. O.

Trigonometric Functions.

For the benefit of those who intend to study trigonometry and surveying, this illustration is inserted here. It will be an advantage and saving of time to be already familiar with the terms and the functions of the science when beginning its study.

P M, sine.
O M, cosine.
A T, tangent.
B S, cotangent.
O T, secant.
O S, cosecant.
M A, versed sine.
B N, conversed sine.

Cubes, Cones, Pyramids, Spheres,

A *cube* is a solid body, having six equal square sides. To find its area. Rule—Multiply area of one side by 6. To find its volume. Multiply the length, the breadth and the thickness together.

Cube.

Find sq. in. in surface of a 12 in. cube.

Answer—12^2 × 6 = 864.

How many cubic in. in a cubic foot?

Answer—$*12^3$ = 1728.

Find cu. ft. in a cu. mile.

Answer—5280^3 = 147197952000.

A *parallelopiped* is a solid body whose six faces are all rectangles. To find its area. Rule—Add areas of its six sides. To find its volume. Same as the cube. How many cubic feet in a wagon bed 10½ feet long, 3 ft. wide and 1¼ ft. deep?

Parallelopiped.

Answer—10½ × 3 × 1¼ = 39⅜.

A *prism* is a solid having three or more rectangular sides, whose ends or bases are parallel plane figures. To find its area. Rule—Add areas of the sides and ends. To find its volume. Multiply the area of one end by the length.

Prism.

Find the area of a triangular prism, each of whose three sides are 10 by 25 inches.

Answers—836.6 sq. in.

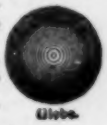
10^2 × .433 × 2 = 86.6 sq. in. in area of the two ends.

10 × 25 × 3 = 750 sq. in. area of sides. 86.0 + 750 = 836.6.

How many cubic inches in above prism, 10 by 25 inches?

Answer—10^2 × .433 = 43.3 × 25 = 1082½ cu. in.

A *globe* or *sphere* is a solid body, bounded by a uniformly curved surface. To find its area. Rule—Multiply the square of diameter by 3.1416; or the square of the circumference by .3183. To find its volume. Multiply the cube of diameter by .5236.


Globe.

How many square in. in the surface; and how many cubic in. in the volume of a globe 12 in. in diameter?

Answer—904.78 cu. in. $12^2 \times 3.1416 = 452.39$ sq. in. $12^3 \times .5236 = 904.78$ cu. in.

How many cubic miles in the earth, its diameter being nearly 8000 miles?

Answer—$2000^3 \times .5236 = 268083200000$ cubic mi.

Find greatest cube inscribed in a 26 in. globe.

Answer—$26 \times .577 = 15$ in.

To find the dimensions of a cube, equivalent in volume to a given globe. Rule—Multiply the diameter of given globe by 806.

To find the diameter of a globe, equivalent in volume to a given cube. Rule—Multiply one side of the cube by 1.2407.

A *cylinder* is a round body of uniform diameter whose ends are parallel plane figures. To find its area. Rule—Multiply the circumference by the length and to the product add the areas of both ends. To find its volume. Multiply the area of one end by length.

Cylinder.

Find the area of a cylinder 30 inches in circumference and 40 inches long.

Answer—1343.24 sq. in.

$30 \times 40 = 1200$ sq. in. in convex surface.

$30^2 \times .07958 \times 2 = 143.24$ sq. in. in the two ends.

Find cubic in. in a cylinder, diameter, 20 in., length 50 in.

Answer—$20^2 \times .7854 \times 50 = 15708$ cu. in.

A *cone* is a solid. which has a circular base and tapers uniformly to a point called vertex.

A *pyramid* is a solid, resembling a cone, having three or more triangular sides.

Cone.

Pyramid.

To find the area of a *cone or pyramid*. Rule—Multiply the circumference or perimeter of the base by the slant height, and to half of the product, add the area of the base.

Find the area or surface of a cone whose circumference at base is 40 in., and slant height 50 in.

Answer—1127.33 sq. in.

$50 \times 40 \div 2 = 1000$ sq. in. in convex surface.

$40^2 \times .07958 = 127.33$ in. base.

To find the volume of a cone or pyramid. Rule—Multiply the area of the base by the height and take ⅓ of the product.

How many cubic feet in a 6 sided pyramid, 10 ft. high, whose perimeter, at base is 15 ft. or each side 2½ ft.?

Answer—54.13 cu. ft.

$2\frac{1}{2}^2 \times 2.598 = 16.24$, area of base. $10 \times 16.24 \div 3 = 54.13$.

Find cu. in. in a cone whose height is 12½ in., and diameter of base 10 in.

Answer—$10^2 \times .7854 = 78.54$ area of base. $78.54 \times 12\frac{1}{2} \div 3 = 32.25$ cu. in.

The solid contents of the cone, globe, cylinder and the cube, all of equal dimensions, are in the ratio of 1, 2, 3 and 3.82 respectively. Thus, taking 1 foot as the height and the diameter; the cone contains .2618; the globe .5236, and the cylinder .7854 of a cubic foot. The cube equals 1 cu. ft.

The *frustum of a cone or pyramid* is the part which remains after cutting off the top, parallel to the plane of the base. To find the area of a frustum. Rule—Multiply the sum of circumferences, or perimeters, by the slant height, and to half of the product, add the area of each base.

Frustum.

Find the *area of a frustum* of a cone, whose slant height is 40 in., its greater circumference, 30 in., and its smaller one, 10 in.

Answer—879.58 sq. in.

$30 + 10 \times 40 \div 2 = 800$, sides. $30^2 + 10^2 \times .07958 = 79.58$, area of bases.

To find the *volume of any frustum*. Rule—Square both ends of one side, if angular, or the diameters of both ends or bases, if round. To the two squares add the product of the given ends or diameters; ⅓ of this sum will be the area of the average base of the frustum of a square pyramid, which multiplied by .7854 equals area of average base of frustum of a cone; multiplied by .433, of a three sided frustum, by 1.7205, of a five sided fr., by 2.5981, of a six sided frustum, by 4.8284, of an eight sided frustum. For volume: multiply average area by perpendicular height.

Find the volume or capacity of a round tank whose diameter is 15 ft. at base, 12 ft. at top, and 10 ft. deep. Ans.—14.37 cu. ft.

$12^2 = 144$ } $183 \times .7854 = 143.73$ sq. ft., area
$15^2 = 225$ } of av. base of Fr. of cone.
$12 \times 15 = 180$

3)549(183, area of av. base of F. of sq. pyr.

$143.73 \times 10 = 1437.3$ cu. ft. $\times 7.48 = 10751$ gallons.

Find sq. ft. of lumber in a wagon tongue; large end, 4½ in. sq., small end, 2½ in., length, 9 ft. (108 in.).

Answer—$4\frac{1}{2} + 2\frac{1}{2}^2 + (4\frac{1}{2} \times 2\frac{1}{2}) \div 3 = 12\,7/12$ sq. in., area of average base; $12\,7/12 \times 108 = 1359$ cu. in. $\div 144 = 9\,7/16$ sq. ft.

How many cu. ft. in a straight log, whose diameter at large end is 3 ft., small end, 2 ft., length 12 ft?

Answer—$3^2 + 2^2 + (3 \times 2) \div 3 \times .7854 = 4.974$ sq. ft., area of average base; $4.97_7 \times 12 = 59.69$ cu. ft.

A *spheroid* or elongated globe has a fixed and a revolving axis. To find its area. Rule—Multiply the revolving axis by the fixed axis, and that product by 3.1416. To find its volume. Rule—Multiply the square of the revolving axis by the fixed axis and that product by .5236. Find area, also the volume of spheroid; revolving axis, 20 in., fixed, 30 in.

Spheroid

$20 \times 30 \times 3.1416 = 1884.96$ sq. in. in area.

$20^2 \times 30 \times .5236 = 6283.2$ cu. in. in volume.

A *cylindrical ring* is formed by bending a cylinder. To find its area. Rule—Multiply sum of inside diam. and thickness of ring, by thickness, and the product by 9.87. To find its volume. Rule—Multiply sum of inside diam. and thickness by square of thickness, and product by 2.467.

Ring.

Find the area, also the volume of a ring whose inner diameter is 15 inches, and whose thickness is 5 inches.

$(15 + 5) \times 5 \times 9.87 = 987$ sq. in. in area. $(15 + 5) \times 5^2 \times 2.467 = 1233.5$ cu. in vol.

To find the dimensions of *greatest cube that can be inscribed in a given globe*. Rule—Multiply the diameter of the globe by .577.

The above material has been drawn from "Ropp's Calculator"—an extremely useful and inexpensive little booklet published by C. Ropp & Sons, of Chicago.

Contents of Rectangular Tanks

Cubic Feet, Gallons, Pounds, and Tons of Water

THIS chart will be found useful for rectangular tank determinations. The dimensions of the tank, all in inches, are given in columns A, C, and D. Then, as will be noted, you can find the number of cubic feet in column E, the gallons in column F, the pounds of water in column G, and the tons of water in column H. As a typical example, let us say that the width of a given tank is 10 inches, the depth 5 inches, and the length 20 inches. How many pounds of water will the tank hold?

How to Use the Chart

Find the 10 in column A and run a straight line over to the 5 in column C and locate the intersection with column B. Then from that point of intersection run over to the 20 in column D, and note the intersection with column C. It will be observed now that column C and J are exactly alike so that perfectly horizontal lines can be drawn between those two columns. In this instance the intersection in column C happens to be through the 10, so simply run a straight line through the 10 in column C and the 10 in column J, as shown by the dotted line, and you have a perfectly horizontal line which gives all of the answers as follows:

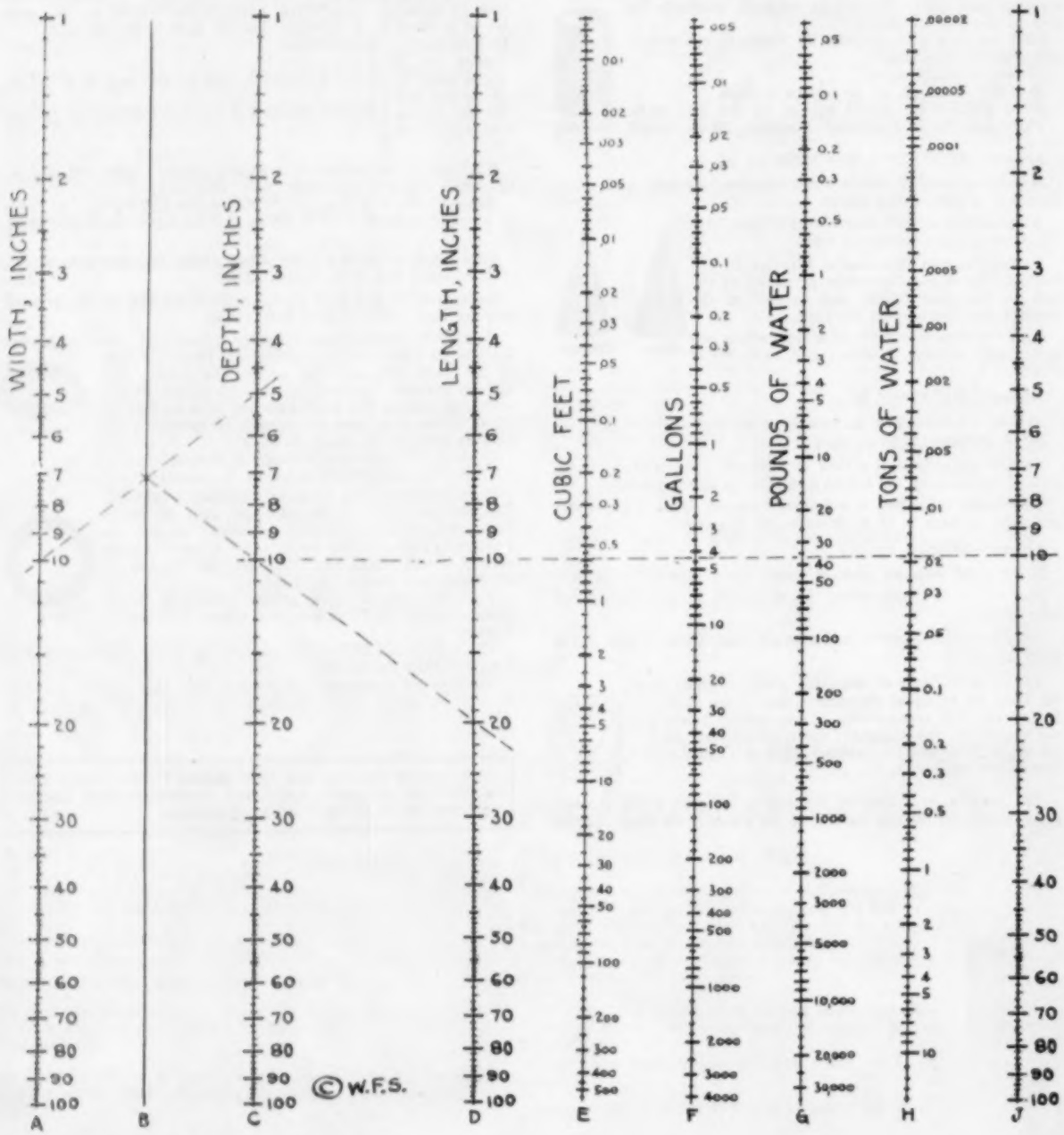
Column E shows that the tank has a volume of nearly 0.6 cu. ft.

Column F shows that the number of gallons is about 4.3.

Column G shows that if the tank contains water the weight will be about 37 pounds.

Column H shows that the number of tons of water is approximately .0185.

Contributed by W. F. Schaphorst, M.E., Newark, N. J.



Contents of Horizontal Cylinders

A Multiple Use Chart for Vertical as Well as Horizontal Tanks, Pipe Lines, Etc.

by J. TARRANT

Assoc. M. Inst. C.E., A.M.I. Mech. E. Ruislip (Middlesex), England

THE alignment chart printed herewith gives a convenient method of finding the contents of cylindrical tanks placed with the axis horizontal for all depths of liquid in the tank.

It is usually the case that only a fair approximation of the tank contents is required, and the calculation by exact formula is not very readily done.

Formulas for horizontal cylindrical tanks contents are generally printed in two forms, one for use when the liquid level is above the centre and the other when the level is below the centre of the tank.

On the chart, the scale relating to the depth of liquid is continuous; that is to say, it applies whether the liquid level be in the upper or lower half of the section.

To use the chart, a straightedge is placed across the scales, and the intersections on the three scales give the related values. Line A gives the ratio of depth of liquid to the diameter of the tank; line B, the diameter of the tank in feet; and line C, the contents, in cubic feet and gallons, for each foot of length of the tank. In the example shown by the line across the chart, a tank 15 feet in diameter in which the contents are 10 feet 6 inches deep, will contain approximately 1,000 gallons per foot of length.

By using the fixed value of h/d = 1, the chart also gives contents per foot of height of a cylinder with vertical axis, and also the contents of full pipes per foot of length.

Sometimes the dimensions of a tank or pipe line will not be in feet, but the chart may still be used. The contents will be in units which correspond to the dimensional units, and the scale of gallons will not apply. For example, if the diameter is taken in inches, the contents, *read on the cubic feet scale*, will be in *cubic inches* per *inch* of length.

The calculation of contents is clearly based on the area of the segment of a circle, which is what the contents scale on line C shows, and the calculation of segmental areas, in any dimensional units, may be made by use of the chart so long as the cubic feet scale is read, and units ascribed to this which correspond to the units used for the diameter. When the diameter is in feet, the area of the segment is in square feet; for meters, the area is in square meters; for inches, in square inches, and so on.

WEIGHTS AND MEASURES

Troy Weight

3.086 grains = 1 carat
24 grains = 1 dwt.
20 dwts. = 1 ounce
12 ounces = 1 pound

Used for weighing gold, silver, and jewels.

Apothecaries' Weight

20 grains = 1 scruple
3 scruples = 1 dram
8 drams = 1 ounce
12 ounces = 1 pound

The ounce and pound in this weight are the same as in Troy Weight.

Avoirdupois Weight

1 grain (Troy) = 1 grain (Apoth.) = 1 grain (Avdp.)

27 11/32 grams = 1 dram
16 drams = 1 ounce = 437.5 grains
16 ounces = 1 pound
25 pounds = 1 quarter
4 quarters = 1 cwt.
2,000 lbs. = 1 short ton
2,240 lbs. = 1 long ton
1 long ton = 1 British ton

Dry Measure

2 pints = 1 quart
1 quart = 67.2 cu. in.
1 British bushel = 1.032 U. S. Bushel
8 quarts = 1 peck
4 pecks = 1 bushel

Liquid Measure

4 gills = 1 pint
16 fluid ounces = 1 pint
2 pints = 1 quart
4 quarts = 1 gallon
1 British Imperial gallon = 1.200 U. S. gallons
1 cubic foot of water contains 7.48 gallons and weighs 62.321 lb.
1 gallon = 231 cu. in.
31½ gallons = 1 barrel
2 barrels = 1 hogshead

Linear Measure

1 mil = 0.001 inch
12 inches = 1 foot
3 feet = 1 yard
5½ yards = 1 rod
40 rods = 1 furlong
8 furlongs = 1 statute mile
5280 feet = 1 statute mile
3 miles = 1 league

Square Measure

1 circular mil = 0.7854 square mils
1,000,000 square mils = 1 square inch
144 square inches = 1 sq. ft.
9 sq. ft. = 1 sq. yard
4 roods = 1 acre = 43560 sq. ft.
30¼ sq. yds. = 1 sq. rod
40 sq. rods = 1 rood
640 acres = 1 sq. mile

Surveyor's Measure

7.92 inches = 1 link
25 links = 1 rod
4 rods = 1 chain
43560 sq. ft. = 1 acre
640 acres = 1 sq. mile
10 sq. chains or 160 sq. rods = 1 acre
36 sq. miles (6 miles square) = 1 township

Mariners' Measure

6.08 feet = 1 fathom
120 fathoms = 1 cable length
8.31 cable lengths = 1 nautical mile
6080 feet = 1 nautical mile
1 nautical mile = 1.15 statute mile
1 knot is a speed of 1 nautical mile per hour

Paper Measure

24 sheets = 1 quire
20 quires = 1 ream
2 reams = 1 bundle
5 bundles = 1 bale

Cubic Measure

1 cu. cm. = .061 cu. in.
27 cu. ft. = 1 cp. yd.
40 cu. ft. = 1 ton (shipping)
231 cu. in. = 1 standard gallon
2150.42 cu. in. = 1 standard bushel
1 cu. ft. = 4/5 of a bushel
1728 cu. in. = 1 cu. ft.
128 cu. ft. = 1 cord (wood)

Household Measure

60 drops = 1 teaspoon
2 teaspoons = 1 dessert spoon
3 teaspoons = 1 tablespoon
16 tablespoons = 1 cup
2 gills = 1 cup
2 cups = 1 pint

METRIC EQUIVALENTS

Linear Measure

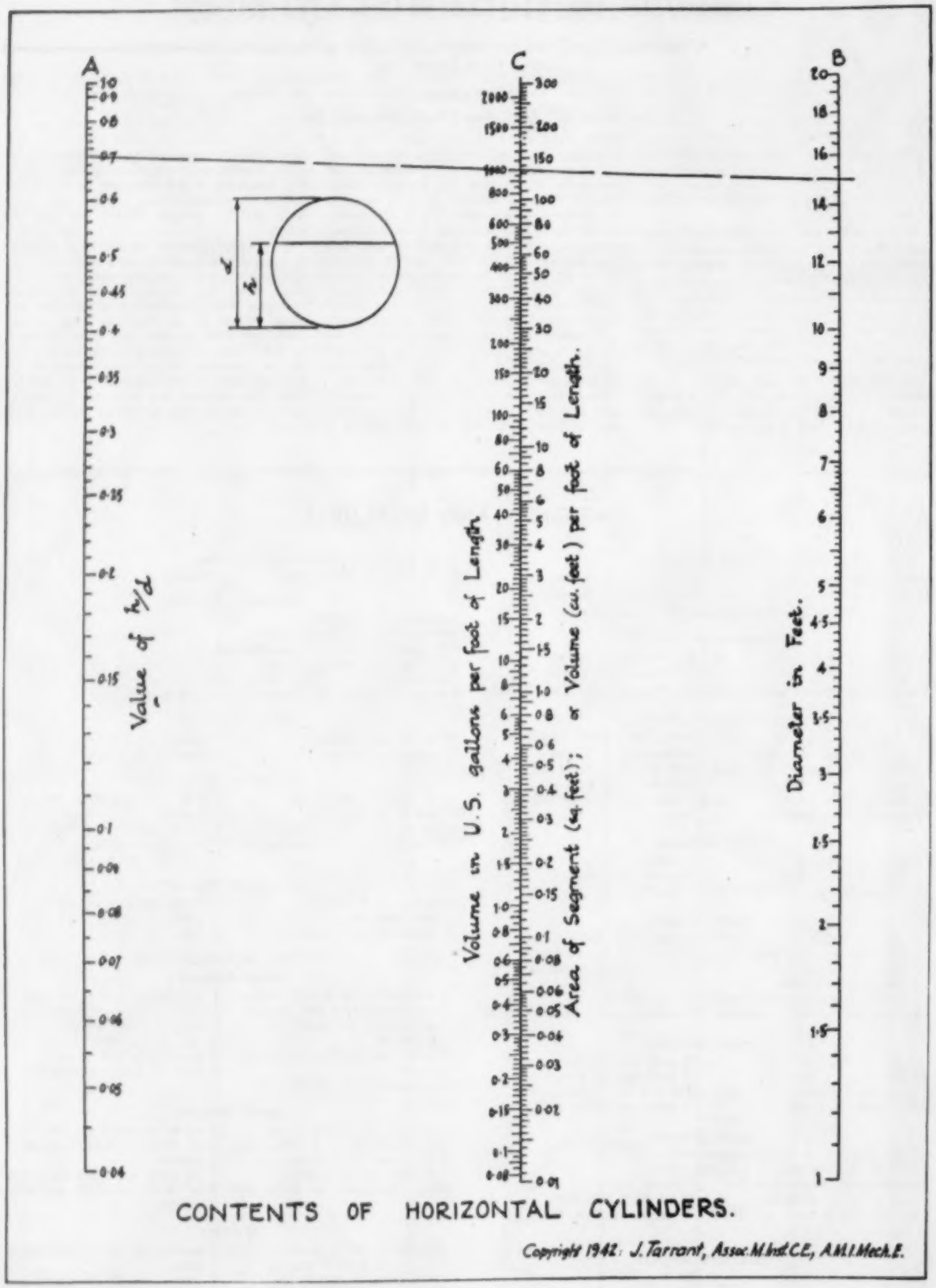
1 millimeter = 0.03937 inches
1 centimeter = 0.3937 inches
1 decimeter = 3.937 in. = 0.328 ft.
1 meter = 39.37 in. = 1.0936 yards
1 dekameter = 1.9884 rods
1 kilometer = 0.62137 mile
1 inch = 2.54 centimeters
1 foot = 3.048 decimeters
1 rod = 0.5029 dekameter
1 yard = 0.9144 meter
1 mile = 1.6093 kilometers

Square Measure

1 sq. cm. = 0.1550 sq. in.
1 sq. decimeter = 0.1076 sq. ft.
1 sq. meter = 1.196 sq. yds.
1 hectare = 2.47 acres
1 sq. kilometer = 0.386 sq. miles
1 sq. in. = 6.452 sq. cm.
1 sq. foot = 9,2903 sq. decimeters
1 sq. yard = 0.8361 sq. meter
1 sq. mile = 2.59 sq. kilometers

Weights

1 dyne = .00102 grains
1 gram = 0.03527 ounces
1 kilogram = 2.2046 lbs.
1 metric ton = 2205 lbs.
1 pound = 0.4536 kilograms
1 metric ton = 1.1023 short tons
1 ounce = 28.35 grams = 437.5 grains



CONTENTS OF HORIZONTAL CYLINDERS.

Copyright 1942: J. Tarrant, Assoc. M. Inst. C.E., A.M.I. Mech. E.

Conversion Factors

The word gallon, used in any conversion factor, designates the U. S. gallon. Likewise, the word ton designates a short ton, 2,000 pounds.

The figures 10^{-1}, 10^{-2}, 10^{-3}, etc., denote 0.1, 0.01, 0.001, etc., respectively.

The figures 10^{1}, 10^{2}, 10^{3}, etc., denote 10, 100, 1000, etc., respectively.

"Parts Per Million," (designated as p.p.m.), is always by weight. As used in the sanitary field, p.p.m. represents the number of pounds of dry solids contained in one million pounds of water. In this field, one part per million may be expressed as 8.345 pounds of dry solids to one million U. S. gallons of water.

Multiply	By	To Obtain
Acres	43,560	Square feet
"	4047	Square meters
Acre-feet	43,560	Cubic feet
" "	325,851	Gallons
" "	1233.49	Cubic meters
Atmospheres	29.92	Inches of mercury
"	33.90	Feet of water
"	76.0	Cms. of mercury
"	14.70	Lbs./sq. inch
Barrels cement	376	Pounds—cement
Bags or sacks-cement	94	Pounds— "
British Thermal Units	777.5	Foot-lbs.
" " "	3.927×10^{-4}	Horse-power-hrs.
" " "	2.928×10^{-4}	Kilowatt-hrs.
" " "	0.2520	Kilogram-calories
" " "	107.5	Kilogram-meters
B.T.U./min.	12.96	Foot-lbs./sec.
" "	0.02356	Horse-power
" "	0.01757	Kilowatts
Centimeters	0.3937	Inches
Centimeters of mercury	0.01316	Atmospheres
" " "	0.4461	Feet of water
" " "	27.85	Lbs./sq. ft.
" " "	0.1934	Lbs./sq. inch
Centimeters/second	1.969	Feet/min.
" "	0.01281	Feet/sec.
" "	0.6	Meters/min.
Cubic centimeters	3.531×10^{-5}	Cubic feet
" "	6.102×10^{-2}	Cubic inches
" "	2.642×10^{-4}	Gallons
" "	10^{-6}	Cubic meters
" "	10^{-3}	Liters
Cubic feet	7.48052	Gallons
" "	1728	Cubic inches
" "	0.03704	Cubic yards
" "	28.32	Liters
" "	2.832×10^{4}	Cubic cms.
" "	0.02832	Cubic meters
Cubic feet/second	0.646317	Million gals./day
" " "	448.831	Gallons/min.
Cubic inches	16.39	Cubic centimeters
" "	5.787×10^{-4}	Cubic feet
" "	1.639×10^{-5}	Cubic meters
" "	4.329×10^{-3}	Gallons
" "	1.639×10^{-2}	Liters
Cubic meters	35.31	Cubic feet
" "	1.308	Cubic yards
" "	264.2	Gallons
" "	10^{3}	Liters
Cubic yards	27	Cubic feet
" "	46,656	Cubic inches
" "	0.7646	Cubic meters
" "	202.0	Gallons
" "	764.6	Liters
Drams	27.34375	Grains
"	0.0625	Ounces
"	1.771845	Grams
Fathoms	6	Feet
Feet	30.48	Centimeters
"	0.3048	Meters
Feet of water	0.3826	Inches of mercury
" " "	0.4335	Lbs./sq. inch
" " "	62.43	Lbs./sq. ft.
" " "	0.02950	Atmospheres
" " "	304.8	Kgs./sq. meter
Feet/sec.	30.48	Centimeters/sec.
" "	18.29	Meters/min.
Foot-pounds	1.286×10^{-3}	British thermal units
" "	5.050×10^{-7}	Horse-power-hrs.
" "	0.1383	Kilogram-meters
" "	3.766×10^{-7}	Kilowatt-hrs.
Foot-pounds/min.	3.030×10^{-5}	Horse-power
" " "	2.260×10^{-5}	Kilowatts
Gallons	0.1337	Cubic feet
"	231	Cubic inches
"	3785	Cubic centimeters
"	3.785×10^{-3}	Cubic meters
"	3.785	Liters
Gallons, Imperial	1.200095	U. S. gallons
" U. S.	0.83267	Imperial gallons
Gallons water	8.3453	Pounds of water
Gallons/min.	2.228×10^{-3}	Cubic feet/sec.
" "	0.06308	Liters/sec.
" "	8.0208	Cu. ft./hr.
Grains (troy)	1	Grains (avoir.)
"	0.06480	Grams
Grains/U.S. gal.	17.118	Parts/million
" /U.S. gal.	142.86	Lbs./million gal.
" /Imp. gal.	14.254	Parts/million
Grams	15.43	Grains
"	0.03527	Ounces
"	980.7	Dynes
Grams/liter	58.417	Grains/gal.
" "	8.345	Pounds/1000 gals.
" "	1000	Parts/million
Hectares	2.471	Acres
Horse-power	42.44	B.T. Units/min.
" "	550	Foot-lbs./sec.
" "	0.7457	Kilowatts
Horse-power (boiler)	33,479	B.T.U./hr.
" " "	9.803	Kilowatts
Inches	2.540	Centimeters
Inches of mercury	1.133	Feet of water
" " "	0.4912	Lbs./sq. inch
" " "	0.03342	Atmospheres
" " "	345.3	Kgs./sq. meter
Inches of water	0.07355	Inches of mercury
" " "	0.03613	Lbs./sq. inch
Kilograms	2.205	Lbs.
Kilograms-calories/min.	51.43	Foot-pounds/sec.
" " "	0.09351	Horse-power
" " "	0.06972	Kilowatts
Kgs./sq. meter	3.281×10^{-3}	Feet of water
" " "	1.422×10^{-3}	Lbs./sq. inch
Kilometers	3281	Feet
"	0.6214	Miles
Kilometers/hr.	0.9113	Feet/sec.
" "	27.78	Centimeters/sec.
Kilowatts	56.92	B.T. Units/min.
"	737.6	Foot-lbs./sec.
"	1.341	Horse-power
"	14.34	Kg.-calories/min.
Liters	0.2642	Gallons
"	61.02	Cubic inches
"	0.03531	Cubic feet
Meters	3.281	Feet
"	39.37	Inches
"	1.094	Yards
Miles	5280	Feet
"	1.609	Kilometers
Miles/min.	88	Feet/sec.
" "	1.609	Kilometers/min.
Milligrams/liter	1	Parts/million
Million gals./day	1.54723	Cubic ft./sec.
Miner's inches	1.5	Cubic ft./min.
Ounces	28.349527	Grams
"	437.5	Grains
"	0.9115	Ounces (troy)
Ounces (fluid)	1.805	Cubic inches
" "	29.57	Cubic cm.
Parts/million	8.345	Lbs./million gal.
" "	0.0584	Grains/U. S. gal.
" "	0.07016	Grains/Imp. gal.
Pounds	16	Ounces
"	7000	Grains
"	453.5924	Grams
"	1.21528	Pounds (troy)

Selections from a booklet of—"Conversion Factors for Engineers"—distributed by The Dorr Co., Stamford, Conn.

Multiply	By	To Obtain
Pounds of water	0.01602	Cubic feet
" " "	27.68	Cubic inches
" " "	0.1198	Gallons
Pounds/cubic foot	0.01602	Grams/cubic cm.
" " "	16.02	Kgs./cubic meter
" " "	5.787×10^{-4}	Lbs./cubic inch
Pounds/foot	1.488	Kgs./meter
Pounds/inch	178.6	Grams/cm.
Pounds/sq. foot	0.01602	Feet of water
" " "	4.883	Kgs./sq. meter
Pounds/sq. inch	2.307	Feet of water
" " "	2.036	Inches of mercury
" " "	0.06804	Atmospheres
" " "	703.1	Kgs./sq. meter
Quires	25	Sheets
Reams	500	Sheets
Square centimeters	0.1550	Square inches
" "	1.076×10^{-3}	Square feet
Square feet	144	Square inches
" "	0.09290	Square meters
" "	2.296×10^{-5}	Acres
Square inches	6.452	Square centimeters

Multiply	By	To Obtain
Square kilometers	247.1	Acres
" "	10.76×10^{6}	Square feet
" "	1.196×10^{6}	Square yards
Square meters	10.76	Square feet
" "	1.196	Square yards
Square miles	640	Acres
" "	27.88×10^{6}	Square feet
" "	2.590	Square Kilometers
Square yards	9	Square feet
" "	0.8361	Square meters
" "	2.066×10^{-4}	Acres
Tons (long)	1016	Kilograms
" "	2240	Pounds
" "	1.12000	Tons (short)
Tons (metric)	10^{6}	Kilograms
" "	2205	Pounds
Tons (short)	2000	Pounds
" "	907.18486	Kilograms
Tons of water/24 hrs.	0.16643	Gallons/min.
Watts	0.05692	B.T.Units/min.
"	0.7376	Foot-pounds/sec.
"	1.341×10^{-3}	Horse-power
"	0.01434	Kg.-calories/min.
Yards	0.9144	Meters

Conversion of °C to °F or °F to °C $= \frac{C}{100} = \frac{F - 32}{180}$

Weights and Measures

Troy Weight

3.086 grains = 1 carat
24 grains = 1 dwt.
20 dwts. = 1 ounce
12 ounces = 1 pound

Used for weighing gold, silver, and jewels.

Apothecaries' Weight

20 grains = 1 scruple
3 scruples = 1 dram
8 drams = 1 ounce
12 ounces = 1 pound

The ounce and pound in this weight are the same as in Troy Weight.

Avoirdupois Weight

1 grain (Troy) = 1 grain (Apoth.) = 1 grain (Avdp.)

27 11/32 grams = 1 dram
16 drams = 1 ounce = 437.5 grains
16 ounces = 1 pound
25 pounds = 1 quarter
4 quarters = 1 cwt.
2,000 lbs. = 1 short ton
2,240 lbs. = 1 long ton
1 long ton = 1 British ton

Dry Measure

2 pints = 1 quart
1 quart = 67.2 cu. in.
8 quarts = 1 peck
4 pecks = 1 bushel
1 British bushel = 1.032 U. S. Bushel

Liquid Measure

4 gills = 1 pint
16 fluid ounces = 1 pint
2 pints = 1 quart
4 quarts = 1 gallon
1 gallon = 231 cu. in.
31½ gallons = 1 barrel
2 barrels = 1 hogshead
1 British Imperial gallon = 1.200 U. S. gallons
1 cubic foot of water contains 7.48 gallons and weighs 62.321 lb.

Linear Measure

1 mil = 0.001 inch
12 inches = 1 foot
3 feet = 1 yard
5½ yards = 1 rod
40 rods = 1 furlong
8 furlongs = 1 statute mile
5280 feet = 1 statute mile
3 miles = 1 league

Square Measure

1 circular mil = 0.7854 square mils
1,000,000 square mils = 1 square inch
144 square inches = 1 sq. ft.
9 sq. ft. = 1 sq. yard
4 roods = 1 acre = 43560 sq. ft.
30¼ sq. yds. = 1 sq. rod
40 sq. rods = 1 rood
640 acres = 1 sq. mile

Surveyor's Measure

7.92 inches = 1 link
25 links = 1 rod
4 rods = 1 chain
43560 sq. ft. = 1 acre
640 acres = 1 sq. mile
10 sq. chains or 160 sq. rods = 1 acre
36 sq. miles (6 miles square) = 1 township

Mariners' Measure

6.08 feet = 1 fathom
120 fathoms = 1 cable length
8.31 cable lengths = 1 nautical mile
6080 feet = 1 nautical mile
1 nautical mile = 1.15 statute mile
1 knot is a speed of 1 nautical mile per hour

Paper Measure

24 sheets = 1 quire
20 quires = 1 ream
2 reams = 1 bundle
5 bundles = 1 bale

Cubic Measure

1 cu. cm. = .061 cu. in.
27 cu. ft. = 1 cp. yd.
40 cu. ft. = 1 ton (shipping)
231 cu. in. = 1 standard gallon
2150.42 cu. in. = 1 standard bushel
1 cu. ft. = 4/5 of a bushel
1728 cu. in. = 1 cu. ft.
128 cu. ft. = 1 cord (wood)

Household Measure

60 drops = 1 teaspoon
2 teaspoons = 1 dessert spoon
3 teaspoons = 1 tablespoon
16 tablespoons = 1 cup
2 gills = 1 cup
2 cups = 1 pint

METRIC EQUIVALENTS

Linear Measure

1 millimeter = 0.03937 inches
1 centimeter = 0.3937 inches
1 decimeter = 3.937 in. = 0.328 ft.
1 meter = 39.37 in. = 1.0936 yards
1 dekameter = 1.9884 rods
1 kilometer = 0.62137 mile
1 inch = 2.54 centimeters
1 foot = 3.048 decimeters
1 rod = 0.5029 dekameter
1 yard = 0.9144 meter
1 mile = 1.6093 kilometers

Square Measure

1 sq. cm. = 0.1550 sq. in.
1 sq. decimeter = 0.1076 sq. ft.
1 sq. meter = 1.196 sq. yds.
1 hectare = 2.47 acres
1 sq. kilometer = 0.386 sq. miles
1 sq. in. = 6.452 sq. cm.
1 sq. foot = 9,2903 sq. decimeters
1 sq. yard = 0.8361 sq. meter
1 sq. mile = 2.59 sq. kilometers

Weights

1 dyne = .00102 grains
1 gram = 0.03527 ounces
1 kilogram = 2.2046 lbs.
1 metric ton = 2205 lbs.
1 pound = 0.4536 kilograms
1 metric ton = 1.1023 short tons
1 ounce = 28.35 grams = 437.5 grains

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